European Journal of Operational Research 232 (2014) 298–306

Contents lists available at SciVerse ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Discrete Optimization

A post-optimization method for the routing and wavelength assignment problem applied to scheduled lightpath demands

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ARTICLE INFO

Article history:
Received 20 May 2009
Accepted 26 June 2013
Available online 18 July 2013

Keywords:
Combinatorial optimization
WDM optical networks
Routing and Wavelength Assignment Problem (RWA)
Scheduled Lightpath Demands (SLDs)
Post-optimization

ABSTRACT

We consider here a NP-hard problem related to the Routing and Wavelength Assignment (RWA) problem in optical networks, dealing with Scheduled Lightpath Demands (SLDs). An SLD is a connection demand between two nodes of the network, during a certain time. Given a set of SLDs, we want to assign a lightpath, i.e. a routing path and a wavelength, to each SLD, so that the total number of required wavelengths is minimized. The constraints are the following: a same wavelength must be assigned all along the edges of the routing path of any SLD; at any time, a given wavelength on a given edge of the network cannot be used to satisfy more than one SLD. To solve this problem, we design a post-optimization method improving the solutions provided by a heuristic. The experimental results show that this post-optimization method is quite efficient to reduce the number of necessary wavelengths.

1. Introduction

We consider a problem related to the Routing and Wavelength Assignment (RWA) problem in wavelength division multiplexing (WDM) optical networks; see e.g. Gagnaire, Kuri, and Koubaa (2009), Kuri, Puech, Gagnaire, Dotaro, and Douville (2003), Ramaswami and Sivarajan (2002) or Zheng and Mouftah (2004) for general references. Fibre-optic networking technology using WDM offers the potential of dividing the bandwidth of a fibre into several channels, each at a different optical wavelength, permitting to carry data in parallel. For a given network topology, represented by an undirected graph $\mathcal{G}$, the RWA problem consists in establishing a set S of traffic demands, also called connection requests, in this network. Different versions of the RWA problem can be found in the literature, depending on the performance metrics and on the traffic assumptions; see for instance (Zang, Jue, & Mukherjee, 2000). Traffic demands may be of three types: static (permanent and known in advance), scheduled (requested for a given period of time and known in advance) and dynamic (unexpected). The typical objectives of RWA can be:

- to minimize the required number of wavelengths under given connection requests,
- to minimize the blocking probability, i.e. the number of rejected traffic demands, under a given number of wavelengths and dynamic connection requests,
- to minimize the maximum number of wavelengths going through a single fibre, also called the *lightpath congestion*,
- to minimize the network load as defined by the fraction of the number of wavelengths used on the overall set of fibre links in the network.

These problems or variants of them have been extensively studied in the last decades; see, among others, (Banerjee & Mukherjee, 1996; Belgacem & Puech, 2008; Chen & Banerjee, 1996; Choi, Golmie, Lapeyere, Mouveaux, & Su, 2000; Jaumard, Meyer, & Thiongane, 2006; Krishnaswamy & Sivarajan, 2001; Kumar & Kumar, 2002; Kuri, 2003; Kuri, Puech, Gagnaire, 2003; Kuri, Puech, Gagnaire, Dotaro et al., 2003; Lee, Kang, Lee, & Park, 2002; Margara & Simon, 2000; Noronha, Resende, & Ribeiro, 2008; Noronha & Ribeiro, 2006; Ramaswami & Sivarajan, 1995; Skorin-Kapov, 2006a, 2006b, 2007, 2008; Zang et al., 2000; Zheng & Mouftah, 2004).

Many of these works consider static demands; the problem is then sometimes called the *wavelength dimensioning problem*, see for instance (Jaumard et al., 2006) where this problem is studied. In this paper, we deal with the case of a set S of Scheduled Lightpath Demands (SLDs). This is relevant because of the predictable and periodic nature of the traffic load in real transport networks, more intense during working hours, see Kuri, Puech, Gagnaire, Dotaro et al. (2003). This case is also much more difficult

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http://dx.doi.org/10.1016/j.ejor.2013.06.050

than the static one, because of the time constraints which do not exist for static demands.

More precisely, an SLD s belonging to S can be represented by a quadruplet $s = (x, y, \alpha, \beta)$, where x and y are some vertices of $\mathcal{G}$ (source and destination nodes of the connection request), and where α and β denote the set-up and tear-down dates of the demand. The routing of $s = (x, y, \alpha, \beta)$ consists in setting up a lightpath (P, w) between x and y, where P is a path, also called route, between x and y in $\mathcal{G}$ and w a wavelength (we do not address here the case where a traffic demand requires several lightpaths). In order to satisfy s, this lightpath must be reserved during all the span of $[\alpha, \beta]$.

When wavelength converters exist, it is not necessary to use a same wavelength on all the links used by a lightpath. Unfortunately, this entails a lot of expense and hence changes the nature of the problem: the aim is then to determine the placement of these converters so that the overall network cost is minimized; see for instance (Chu, Li, & Chlamtac, 2002). When there are no wavelength converters in the network, as it will be assumed in this paper, the *wavelength continuity constraint* is imposed: the same wavelength must be used on all the links used by a lightpath. Moreover, at any given time, a wavelength can be used at most once on a given link; in other words, if two demands overlap in time, they can be assigned the same wavelength if and only if their routing paths are disjoint in edges. This constraint is often called the *wavelength clash constraint*.

We address in this paper the problem consisting in minimizing the number W of wavelengths required to establish all the SLDs. This problem is NP-hard, even if we do not take the time-windows into account; see Chlamtac, Ganz, and Karmi (1992). A solution of this problem is defined by specifying, for each SLD, the lightpath chosen for supporting the connection, i.e. a route and a wavelength, so that there is no conflict between any two lightpaths (let us recall that two lightpaths are in conflict if they use the same wavelength, they have at least one edge in common and the corresponding demands overlap in time). Several approximate or exact methods have been proposed in the literature to deal with this NP-hard problem for static demands or for SLDs; see Gi Ahn, Lee, Chung, and Choo (2005), Jaumard et al. (2006), Kuri, Puech, Gagnaire, Dotaro et al. (2003), Lee et al. (2002), Margara and Simon (2000), Park, Yang, and Bang (2007), Saradhi and Gurusamy (2005), Skorin-Kapov (2006a, 2006b, 2007), Wauters and Demeester (1996) and Zang et al. (2000).

The greedy method proposed by in Skorin-Kapov (2006b), which has been designed initially to deal with the case where SLDs may require several lightpaths simultaneously, gives very satisfying results in a very small amount of time and is, with this respect, among the most efficient heuristics. Its application to our problem, though we do not consider here the case where a traffic demand requires several lightpaths, will be used as a benchmark for measuring the performance of our approach. Indeed we propose in this paper a post-optimization method in order to improve the results given by other heuristics. The CPU time of the overall method will naturally increase, but it will remain acceptable to deal with SLDs: since the demands are known in advance, the allotted time to provide a solution is relatively large (unlike the case where demands are unexpected, and for which routings must be computed dynamically).

The greedy algorithm derived from Skorin-Kapov (2006b) and the post-optimization method are presented in Section 2. In Section 3, we apply these methods on different types of instances and we analyse the obtained results. Finally we conclude in Section 4.

2. Resolution methods

We describe in this section the different heuristics that we apply to deal with RWA. Let us recall that the aim consists in minimizing the number W of wavelengths required to establish a given set S of demands. We first present in Section 2.1 the greedy algorithm derived from Skorin-Kapov (2006b); we propose in Section 2.3 a slight modification of this algorithm so that it can be repeated. The post-optimization method is described in Section 2.2.

2.1. The greedy algorithm

The greedy algorithm derived from Skorin-Kapov (2006b) consists in considering the wavelengths one by one, and in trying to route as many SLDs as possible with each wavelength. For each wavelength w, the SLDs are examined following some prescribed order $\prec$; we set $s' \prec s$ if s' is examined before s.

More precisely, let w be the current wavelength and $s = (x, y, \alpha, \beta)$ be the current SLD. We consider a graph $\mathcal{H}(s)$ obtained from $\mathcal{G}$ by removing all the edges unavailable for the routing of s with w, i.e. edges that are contained in lightpaths corresponding to SLDs already routed with the wavelength w and which overlap s in time. According to this construction, any edge of $\mathcal{H}(s)$ could be used to route the demand s with wavelength w without inducing any clash with previously established SLDs. Thus, if there exists at least one path between x and y in $\mathcal{H}(s)$, we attribute the shortest possible path P_s to the SLD s as well as the wavelength w; otherwise s is put aside and will be dealt with latter using another wavelength. Then we move up to the next not yet established SLD with respect to the prescribed order.

When all the SLDs have been examined, we move up to the wavelength $w + 1$ and try to route the remaining SLDs. The algorithm stops as soon as all the SLDs have been established, and returns the current value of w.

This algorithm is given in Fig. 1 and will be referred to as G.

2.2. The post-optimization method

The post-optimization method presented in this paper aims at improving the results provided by the greedy heuristic depicted above, though it can be applied to any heuristic permitting to solve the addressed problem or even to other variants of this problem. It consists in minimizing the overall values of the wavelengths of the established lightpaths in order to try to minimize the total number of wavelengths W.

The principle of this method is the following: for any $w \in \{2, \ldots, W\}$, we try to empty the set of SLDs routed with w, at least partially; this set will be called the *layer* w in the following. This is done by trying to assign a smaller wavelength $(1, 2, \ldots, w - 1)$ to the demands of the layer w, which leads us to rearrange the wavelengths assigned to the SLDs of these lower

Input: A network $\mathcal{G}$; a set S of SLDs
Output: for each $s \in S$: a lightpath (P_s, w_s); $W = \max_{s \in S}(w_s)$

$w \leftarrow 0$
$N \leftarrow 0$
$\forall s \in S$, $(P_s, w_s) \leftarrow (\emptyset, 0)$
While $N < |S|$
  $w \leftarrow w + 1$
  For $s \in S$ (with $s = (x, y, \alpha, \beta)$), if s is not established ($w_s = 0$)
    $\mathcal{H}(s) \leftarrow \mathcal{G}$
    For $s' \in S$ with $s' \prec s$ (and $s' = (x', y', \alpha', \beta')$)
      If $w_{s'} = w$ and $[\alpha, \beta] \cap [\alpha', \beta'] \neq \emptyset$
        Remove the edges of $P_{s'}$ from $\mathcal{H}(s)$
    If there exists a path between x and y in $\mathcal{H}(s)$
      Assign the lightpath (P_s, w) to s where P_s denotes a shortest path between x and y in $\mathcal{H}(s)$
      $N \leftarrow N + 1$
$W \leftarrow w$.

Fig. 1. Greedy algorithm G.