A Weighted Iterative Conflict Reducing Algorithm for Sliding Scheduled Lightpath Provisioning in WDM Optical Networks

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Abstract. In WDM optical networks, the consistent variation of quality of service (QoS) demand has conducted the advent of sliding scheduled traffic, which does not have a rigid deadline and allows flexible sliding within a large time window. In this paper, the static sliding scheduled lightpath demand (SSLD) provisioning problem is formulated into a weighted partition coloring model. Then, a heuristic algorithm named weighted iterative conflict reducing (WICR) is proposed to solve the SSLD provisioning problem by iteratively reducing conflict degree and minimizing the redundant hops. Simulation results show that our approach can efficiently reduce the overall route length with the same wavelengths utilization performance compared to previous heuristics.

Introduction

The wavelength-division multiplexing (WDM) technology deploys frequency-division multiplexing in the optical frequency domain, where multiple wavelength-division multiplexed channels can be operated on a single fiber simultaneously [1]. In WDM optical networks, a QoS-guaranteed service of some successive erlangs, which allows the serving time flexibly sliding within a larger time window, is called a sliding scheduled lightpath demand (SSLD) [2]. Many researches have been conducted to investigate the sliding scheduled provisioning problem (SSPP) under various traffic models [3]. Generally, SSLD provisioning problem can be classified into dynamic and static problems according to whether the set of SSLDs is known in advance [4, 5]. This work proposes a weighted iterative conflict reducing (WICR) algorithm for the static SSLD provisioning problem.

The rest of this paper is organized as follows. Section 2 describes the general WDM network model for the corresponding SSPP. The heuristic algorithm is proposed in Section 3 to solve SSPP. Section 4 presents the simulation results and compares the performance of the proposed WICR algorithm with its counterparts. Finally, the conclusion is given in Section 5.

Problem statement

The topology of a WDM network is modeled as an undirected graph $G(V,E)$, where V is the set of nodes and E is the set of fiber links. We assume that $\mathbf{\Lambda}$ is the set of wavelength channels used for provisioning and T is the overall time slot set. Each time slot $t \in T$ represents a certain period of time and all the time slots are assumed to be congruent. Besides, it is assumed that the optical network does not have any wavelength converters so that all the lightpaths are subject to wavelength continuity constraint [5]. Therefore, each lightpath maintains a static route of $G(V,E)$ and occupies a constant wavelength $\lambda \in \mathbf{\Lambda}$ throughout the links on this route.

In the aforementioned model, a number of SSLD requests, denoted by $\mathbf{R} = \{R_1, R_2, \ldots, R_N\}$, needs to be accommodated within a certain period of time. Each request can be denoted by a tuple $R_r = (s_r, d_r, [\alpha_r, \beta_r], h_r)$, where s_r is the source node; d_r is the destination node; h_r denotes the required number of serving time slots for the request; and $[\alpha_r, \beta_r]$ represents the time window for the request (α_r is the earliest starting time slot and β_r is the latest ending time slot). Notice that the number of serving time slots should be no larger than the size of this time window, i.e. $h_r \le \beta_r - \alpha_r + 1$, otherwise the network is not able to accommodate the request anyway.

For each coming request, there should be a number of possible routes from the source node s_r to the destination node d_r. On one hand, longer paths are unfavorable for practice consideration, due to signal attenuation and the waste of resource; on the other hand, a number of candidate routes, which are a little longer than the shortest route, are also indispensable, in case there is not enough assignable wavelength channels to avoid congestion in the network. Therefore, a kth shortest path buffer is adopted here, stipulating that no more than k candidate paths are selected in the buffer and each selected path is no more than δ hops longer than the shortest one [6].

The set of candidate paths in the buffer is denoted by P_r. Similarly, the set of all the feasible serving time windows for request r is defined as S_r, with each candidate time window $s_r \in S_r$ satisfying $s_r \in [\alpha_r, \beta_r]$. With path p_r and serving time window s_r being determined, a wavelength channel λ_r could be subsequently assigned to the lightpath to accommodate the coming request. For the sake of simplicity, it is assumed that the number of wavelength channels is always sufficient to accommodate the finite SSLD requests, thus occurrence of blocking of the sliding scheduled traffic is not going to be discussed in this paper. It is also assumed that the path lengths of all hops are equal, so the route length of path p_r is determined by the number of its hops. After a certain route is selected from the candidate path buffer, the amount of redundancy introduced by this step can be hence evaluated. We use the number of additional hops (compared with the shortest route) w_r to represent the weight value of the lightpath for request R_r.

With the definition given above, a decision factor $\varphi_r = (p_r, s_r, w_r)$ is adopted in this paper to determine which wavelength channel λ_r should be assigned to request R_r. The set Φ_r denotes the set of all candidate decision factors for request R_r.

Since the number of wavelength channels is often limited in realistic scenario, it is better to have more spare wavelength channels in case the service volume fluctuates during the next period [7]. In other words, the optimal choice of decision factors should minimize the number of wavelength channels used in current period of time. Therefore, the primary objective for SSLD provisioning problem is to minimize the number of wavelength channels used for accommodating all these requests i.e.

$$Z_{PO} = \min_{\varphi_r \in \Phi_r} \{ |\mathbf{\Lambda}| \} \tag{1}$$

where $|\mathbf{\Lambda}|$ denotes the number of different elements in the wavelength channel set $\mathbf{\Lambda}$ and φ_r is the decision factor. In addition, smaller overall route length is also favorable for practice consideration. Hence, the secondary objective is to minimize the overall route length of the lightpaths i.e.

$$Z_{SO} = \min_{\varphi_r \in \Phi_r} \{ \sum_{r=1}^{N} | p_r | \} \tag{2}$$

where $| p_r |$ denotes the number of hops in route p_r.

Heuristic scheme for SSLD problem

A wavelength conflict graph can be deduced from the combination of a path conflict graph and a time conflict graph with the concept of mixed partition coloring model [8]. In this section, we propose a weighted path-time conflict graph based on the wavelength conflict graph [9]. Instead of calculating time conflict degree and path conflict degree respectively, the integrated path-time conflict degree can be calculated with a single weighted path-time conflict graph. The overall redundancy degree of the network can also be calculated with the help of weighted path-time conflict graph.

Weighted path-time conflict graph. An example of three requests is presented to illustrate the abstract concept of path-time conflict graph. The corresponding WDM network model $G(V,E)$ is given in Fig. 1, where the set of nodes is denoted by $V=\{1,2,3,4,5\}$ and the set of links is denoted by $E=(a,b,c,d,e,f)$. Assume that there are three SSLD requests to be accommodated, namely $R_1=(1,3,[1,3],1)$, $R_2=(1,2,[1,3],2)$ and $R_3=(2,3,[1,2],1)$. As for the k th shortest path buffer, a maximum of four candidate paths ($k=4$) is allowed to be cached and the largest tolerable redundancy is 1 ($\delta=1$).

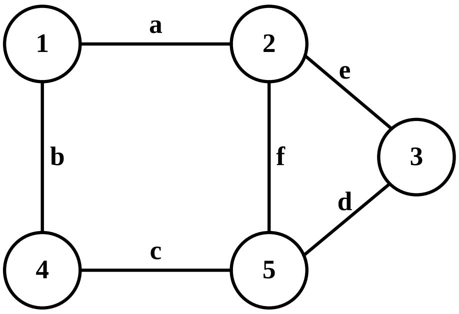


Fig. 1 An example of network topology

For each request R_r, the decision factor Φ_r is denoted as a set of nodes in the weighted path-time conflict graph. The path-time conflict graph of the given example is illustrated in Fig.2. In this example, request R_2 contains two candidate decision factors: candidate decision factor $(a,[1,2],0)$ is colliding with the first and second decision factor in Φ_1 and $(a,[2,3],0)$ is colliding with the second decision factor in Φ_1.

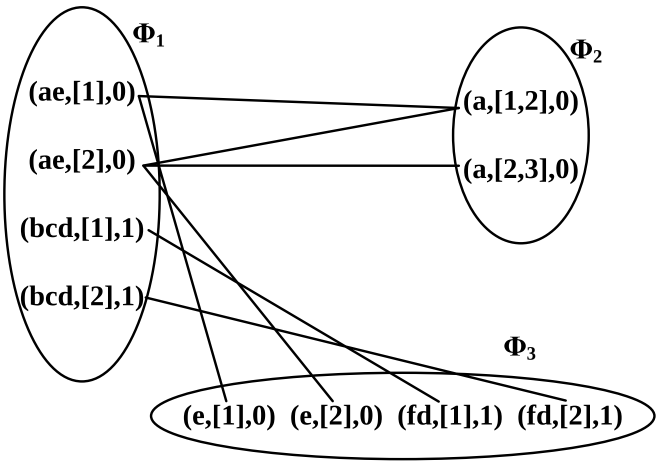


Fig. 2 Weighted path-time conflict graph

The number of line segments linking different requests R_a and R_b in a path-time conflict graph, is defined as the path-time conflict value $|CV(R_a,R_b)|$. Therefore, the corresponding path-time conflict degree $TPC(R_a,R_b)$ can be calculated by the formula

$$TPC(R_a,R_b)=\frac{|CV(R_a,R_b)|}{|\Phi_a||\Phi_b|} \tag{3}$$

where $|\Phi_a|$ and $|\Phi_b|$ denote the number of decision factors in the corresponding request node.

Assume that the mesh network has many uncertain factors so that the probability of selecting a certain decision factor is unknown. In this paper, we heuristically assume that those possibilities of selecting every decision factors $\varphi_r \in \Phi_r$ are congruent within each buffer, i.e., $P(\varphi_r) = |\Phi_r|^{-1}$. Therefore, the expectation of overall redundant hops for request R_r can be calculated by

$$RD_r = \sum_{\varphi_r \in \Phi_r} P(\varphi_r) \cdot w_r = \frac{1}{|\Phi_r|} \sum_{\varphi_r \in \Phi_r} w_r \tag{4}$$

where $|\Phi_r|$ denotes the number of decision factors in the candidate decision factor buffer. In this formula, RD_r is named as the redundancy degree, or the conditioned route length, of request R_r. Furthermore, we define the redundancy degree (or the conditioned overall route length) of the whole network as

$$RD = \sum_{r=1}^{N} RD_r \tag{5}$$

WICR algorithm. Now we present a heuristic algorithm named weighted iterative conflict reducing (WICR) algorithm, which iteratively reduce the path-time conflict of different requests and utilize a weight value to ensure the minimization of overall route length (or conditioned overall route length). WICR is based on the idea of the maximum conflict degree first conflict reducing (MCDF-CR) algorithm in [9].

In WICR algorithm, a weighted value is introduced to ensure that the redundancy degree is minimized within each iteration, under the condition of not introducing any additional wavelengths. Apart from a weight value, WICR is also slightly different with MCDF-CR as for the conflict reducing method. The core idea of conflict reducing in WICR is to reduce the conflict of the top two requests in the measurement of path-time conflict degree in the remaining conflict graph. After the decision step, the two request nodes will be refreshed and the conflict graph will be updated accordingly. Particularly, an additional step should be executed to accommodate the last uncolored request node when the total number of requests is odd. WICR algorithm is presented in Algorithm 1.

Algorithm 1: WICR algorithm

1: Calculate the candidate decision factor set Φ_r for all the requests.

2: Generate the original weighted path-time conflict graph.

while more than two requests is uncolored **do**

3: Find the request R_x and R_y which has the maximum conflict degree $TPC(R_x, R_y)$ among all undecided requests.

4: Choose a pair of $\varphi_x \in \Phi_x$ and $\varphi_y \in \Phi_y$ so that $TPC(R_x, R_y)$ is minimized.

if there are equal choices for φ_x and φ_y, **then**

4: Make sure that the redundancy degree RD of the network is minimized by this step.

5: Assign two different wavelength channels to request R_x and R_y if they are still in conflict, otherwise assign a same wavelength channel to them (assigned wavelength channels should avoid conflict with colored requests).

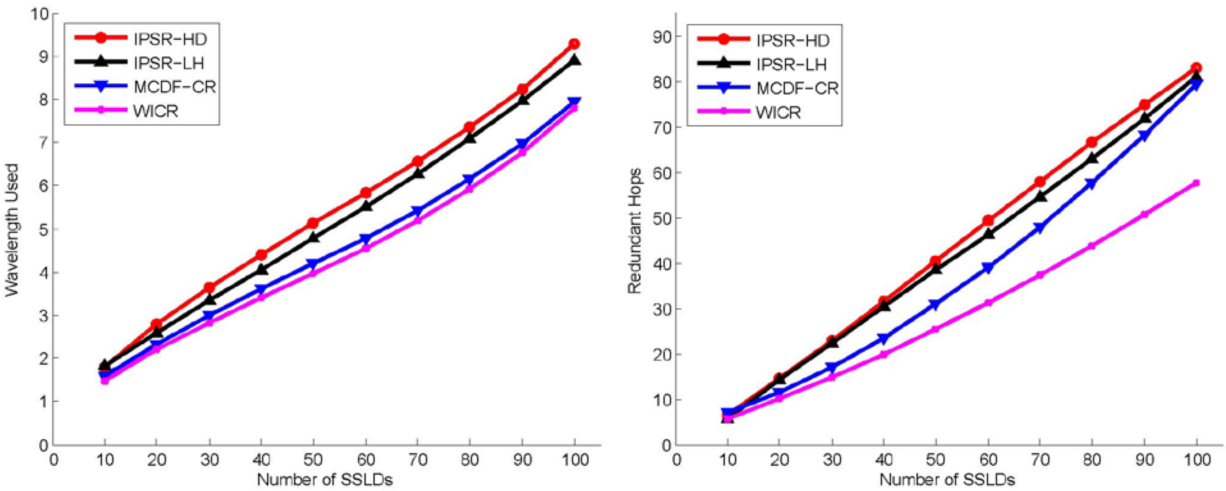
6: Remove candidates in Φ_x and Φ_y except the selected φ_x and φ_y, mark these two request nodes colored, and update the weighted path-time conflict graph.

end while

7: Assign a wavelength channel to the remaining request if there is a single uncolored request left.

Simulation Results

In this section, we evaluate the performance of the proposed WICR by comparing it with IPSR-HD, IPSR-LH [6] and MCDF-CR [9]. A representative 24 node US topology is adopted as the model of this simulation, where a 24h period is equally sliced into $K = 48$ time slots. The 3rd order polynomial fitted simulation results are given in Fig. 3. From the results in Fig. 3(a), it is observed that WICR can only slightly improve the wavelength utilization compared with other algorithms. However, WICR greatly outperforms IPSR and MCDF-CR, as shown in Fig. 3(b), under the measurement of overall route length because the overall redundancy hops of the requests is significantly reduced by WICR, especially for large number of SSLD requests. This improvement in overall route length performance can be attributed to the following reasons. First, WICR copes with the joint conflict degree from a more integrated perspective, i.e, weighted path-time conflict graph, and it increases the computational complexity to some extent due to the update of a complex conflict graph instead of two relatively simple graphs within each iteration. Second, the approach IPSR and MCDF-CR is not designed to minimize the overall route length due to their respective criteria. Finally, the more equal choices there are for reducing the same amount of conflict degree, more efficient WICR tends to be in minimizing the overall route length due to the absence of decision mechanisms in other algorithms.



(a) (b)

Fig. 3. Comparison between WICR, MCDF-CR and IPSR with k =10, δ=4, K=48.

Conclusions

We propose the WICR algorithm based on the MCDF-CR algorithm, to improve the performance of wavelength utilization and overall route length in the SSLD provisioning problem. Compared with previous algorithms, WICR is definitely more advantageous in reducing the overall route length of the optical network, and its wavelength utilization is slightly optimized. Within each iteration, the calculation of a joint conflict graph and route weights may contribute to the overhead brought by the iterative algorithm. Admittedly, the time cost of this algorithm will become a knotty problem when the consistently fluctuating service volume makes the provisioning problem more complicated. Therefore, in the future research, the computational complexity reduction of the proposed algorithm with a not worsening performance will be an increasingly important issue.

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