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Routing and dimensioning in optical WDM networks for dynamic traffic using post-optimization approach

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ABSTRACT

Until now, optimization problems have been considered for routing and resource allocation of static traffic. In this paper, we formulate an integer optimization problem which jointly considers routing and dimensioning in WDM networks in the pre-optimization stage. Since the integer optimization problems are computationally difficult to solve, therefore the integer constraints of the integer optimization problem are relaxed using LP relaxation in the pre-optimization stage. The LP relaxation technique computationally makes the optimization problem to give solutions in short duration of time for various networks. The optimal results obtained from the pre-optimization stage are rounded to integer values in the post-optimization stage which give the numbers of wavelength channels. The solutions obtained from the pre-optimization stage are utilized jointly for routing and dimensioning in the post-optimization stage for dynamic traffic. The link blocking probabilities have been considered as a merit of quality of service for dynamic traffic in different WDM networks. It has been shown through simulations that the proposed two stage optimal routing and dimensioning technique outperforms existing routing and undimensioning WDM networks in various network scenarios.

1. Introduction

Routing and network dimensioning are key technical factors in optical WDM networks which have high impact on network cost and performance [1]. In optical WDM networks, connection requests may either be static, scheduled, or dynamic [2,3]. When lightpath requests (network traffic) between end-to-end nodes are known, it is considered to be static which remains active in the network for long time (typically from weeks to years). Similarly, when set-up and tear-down information between end-to-end nodes in a network are known, it is considered to be scheduled which remains active in the network for a time duration ranging from minutes to weeks. Finally, network traffic is termed to be dynamic which have random arrival times and unknown short durations typically ranging from seconds to minutes to remain active in the network. The assignment of a unique route (path) to a connection request from a set of all available routes in a network is called routing [4–6]. Network dimensioning is an approach in optical networks to determine the desired capacity on each link in numbers of wavelengths to meet the required quality of service in terms of blocking probability and to minimize the network cost [7–10].

Different optimization problems have been proposed in literature for routing of static traffic in optical networks using linear programming (LP), integer linear programming (ILP), or mixed integer linear programming (MILP) [5,11–14]. The goal of these optimization problems is to establish all connection requests while utilizing minimum numbers of network resources. An alternate objective of these optimization problems is to establish the maximum number of connections between source-destination (s-d) pairs for a fixed amount of available network resources including link capacities and switch ports. However, static optimization problems for both ILP and MILP, are known to be NP-complete which are computationally difficult to solve [15–17]. However, two systematic approaches have been considered to reduce the complexity associated with ILP problems in [17] which are called LP relaxation and Lagrangian relaxation methods. In LP relaxation method, the integer variables are set equal to linear and constraints are modified. Both approaches are shown to have similar lower bounds and leads to shortest path routing. The post optimization results obtained from the ILP formulation in [6] have also been utilized for dynamic routing of lightpath connections which resulted in lower blocking probabilities in WDM networks. However, it cannot be utilized for dimensioning of WDM networks as the optimization model in [6] is constrained by the given known values of link capacities. Similarly, the optimization model in [6] selects optimal paths from a set of available paths which will not result in the same optimal path if the link capacity constraint is relaxed. Finally, the optimization model in [6] has been shown infeasible at higher values of normalized traffic load in WDM networks.

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Generally, heuristic approaches are proposed in literature for routing of dynamic traffic which include fixed routing based on shortest paths using Dijkstra's algorithm, alternate routing, and adaptive routing [4,18–21]. The main objective of these heuristic approaches for dynamic traffic is to minimize the network blocking probability or to maximize the network throughput subject to the available resources. Fixed routing is simple compared to alternate routing, but it has higher network blocking probability. Adoptive routing leads to lower blocking probability, but it is more time consuming in searching for dynamic routes in a network based on the current network states.

Network dimensioning is classified into deterministic and statistical dimensioning methods. Deterministic method forecasts network traffic, solve the static optimization problem for assigning network resources to static traffic, and update network resources every 6 to 12 months. It cannot not be utilized for dynamic traffic. Similarly, statistical dimensioning is further classified into two known statistical models including first passage model and blocking model. Both models differ regarding the assumptions to support the set of known lightpath connections. Both models also assume similar numbers of wavelengths on all links, but this may not always be appropriate. In the first passage model, lightpaths arrive randomly to the network according to a statistical model and keep on increasing until the first rejection occurs after a specific time period [8,22–24]. In this model, the rate of arrival on average is assumed to be higher than the rate of departure of lightpath requests. In the blocking model, both arrival and departure are assumed to follow a statistical model [2,7,9,25,26]. However, the rate of arrival and departure of lightpath connections are assumed to be equal and the network will remain in the state of equilibrium. An heuristic approach is also proposed in [27] which considers routing in the initial stage and then considers dimensioning of ring network for dynamic traffic in the second stage. However, these models consider shortest path routing which will overcast the numbers of wavelengths required on each link in case of assuming similar wavelength set required on all links.

Until now, average network blocking probability has been a factor of merit in the literature to show the performance of dynamic traffic in WDM networks [9]. It can be easily verified in a network with dynamic traffic that some links have blocking probabilities higher than the desired level of performance while other have lower blocking probabilities. However, the average network blocking probability will meet the desired threshold (2% to 5%). This is due to the existing routing techniques which utilizes some links more often then the other links. The congestion on the highly utilized links is also higher than the congestion on the under utilized links, keeping the same numbers of wavelength channels on all links. In this work, we formulate the optimization model which will consider both optimal routing and dimensioning of WDM networks in the pre-optimization stage. The results obtained from the optimization model in terms of link capacities (network dimensioning) and routes for each s-d pair will be utilized in the post-optimization stage for dynamic traffic. The integer constraints in the optimization problem are relaxed to linear constraints using LP relaxation methods in the pre-optimization stage which computationally makes the optimization problem to give solutions for a wide range of networks in linear time. However, the linear values from the relaxed problem are rounded to integer values for integer numbers of wavelength channels in the post-optimization stage. Finally, we shall consider link blocking probabilities and s-d pair blocking probabilities as a merit of quality of service for dynamic traffic in WDM networks in this work.

The paper is organized as follows. Section 2 describes the optimization model which jointly considers routing and dimensioning of WDM networks. Section 3 consists of traffic model and WDM networks. It also presents performances of the proposed optimization model for dynamic traffic in WDM networks by utilizing the results obtained from the pre-optimization stage through simulation results in different network scenarios. Finally, Section 4 concludes the paper.

2. Two-stage WDM network design

2.1. Pre-optimization stage: routing and dimensioning model

The network parameters, traffic parameters, and decision variables used in the optimization problem for routing and dimensioning R&D model are listed below.

- **Network parameters**
  $\mathscr{N}$: Set of OXC switch nodes.
  $\mathscr{L}$: Set of directed links, where each directed link $l \in \mathscr{L}$ is a single fiber for transmission in one direction.
  $\mathscr{L}_n^{\text{in}}$: Set of directed links at the input of node n
  $\mathscr{L}_n^{\text{out}}$: Set of directed links at the output of node n
  $\mathscr{S}$: Set of active s-d pairs with nonzero traffic.
- **Traffic parameters**
  α^s: Lightpath arrival rate in traffic units (TUs) for s-d pair s, where each lightpath is assumed to take up a full wavelength.
- **Decision variables**
  $W_{\max} \in \mathbb{Z}^+$: Maximum number of wavelengths assigned on a link l in WDM network.
  $\lambda_n^{\text{in}} \in \mathbb{Z}^+$: Number of switch ports assigned at the input of a node n
  $\lambda_n^{\text{out}} \in \mathbb{Z}^+$: Number of switch ports assigned at the output of a node n
  $f_l^s \in \{0,1\}$: Traffic flow on link l for s-d pair s; which is equal to 1 if traffic flows on link l for s-d pair s, 0 otherwise.

Objective: The goal of the multi-objective optimization problem in (1) is to minimize the maximum indexed of a wavelength utilized on any link in WDM network and the total numbers of switch ports at the input/output of OXC switch nodes.

$$\text{minimize } W_{\max} + \sum_{n \in \mathscr{N}} (\lambda_n^{\text{in}} + \lambda_n^{\text{out}}) \tag{1}$$

Constraints:
The maximum index of a wavelength assigned on a link l is

$$W_{\max} \geqslant f\left(\sum_{s \in \mathscr{S}} \alpha^s f_l^s\right), \quad \forall\, l \in \mathscr{L} \tag{2}$$

The total numbers of switch ports assigned at the input of a destination OXC switch node are

$$\lambda_n^{\text{in}} \geqslant f\left(\sum_{s \in \mathscr{S}: n = s(1)} \alpha^s f_l^s\right), \quad \forall\, n \in \mathscr{N}, \forall\, l \in \mathscr{L}_n^{\text{in}} \tag{3}$$

The total numbers of switch ports assigned at the output of a source OXC switch node are

$$\lambda_n^{\text{out}} \geqslant f\left(\sum_{s \in \mathscr{S}: n = s(0)} \alpha^s f_l^s\right), \quad \forall\, n \in \mathscr{N}, \forall\, l \in \mathscr{L}_n^{\text{out}} \tag{4}$$

$f(\sum_{s \in \mathscr{S}} \alpha^s f_l^s)$ is a function of the traffic flow for all s-d pair s on link l and rate of flow of traffic for s-d pair s which gives the required numbers of wavelengths in (2) using traffic multiplexing. The idea of traffic multiplexing on a link l is available in [6]. Let us consider 4 switch nodes in Fig. 1. Consider lightpath requests between s-d pair $S_1 = (1,4)$ and s-d pair $S_2 = (2,4)$. Consider 5 Erl of traffic between each s-d pair.

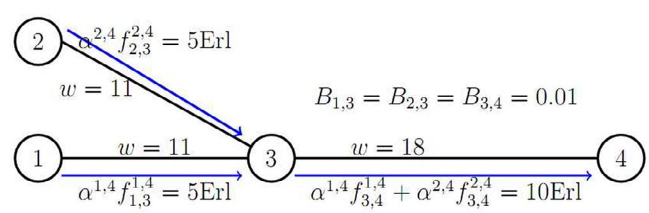

Fig. 1. A network with 4 nodes and 3 directed links.

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