



Online bandwidth provisioning in all optical interconnection networks of data centers: Throughput maximizing approach[☆]



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ABSTRACT

Blocking rate as the key quality of service (QoS) metric, is traditionally addressed in light-path establishment in wavelength division multiplexed (WDM) optical networks while network throughput and link utilization, on the other hand, are arguably of high significance for network providers. To address this issue, we propose light-path establishment algorithm paying close attention to maximizing the network throughput and also, the total amount of transmitted data while minimizing the blocking rate. The proposed algorithm exploits request buffering to attain pseudo-static traffic out of the dynamic traffic. We also incorporate the load balancing by means of quadratic routing, which in turn, results in further reducing the blocking rate. We develop an analytical framework as well as comprehensive simulations for performance evaluation. Obtained results highlight the fact that the proposed algorithm is capable of efficiently increasing the average link utilization and network throughput while ensuring the desired QoS requirements.

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1. Introduction

In order to fulfill the ever increasing traffic demand of Internet, research interests have grown towards ultra-high-rate optical networking. In WDM networks, multiple wavelength channels are used to transmit data through optical fibers. The state of the art optical networks consist of optical links as well as the optical switches known as reconfigurable optical add/drop multiplexers (ROADM) [1]. One of the substantial problems in all optical networks has been known to be the routing and wavelength assignment (RWA) problem where the goal is to find a route for each incoming request followed by assigning an idle wavelength channel. Note that the RWA problem is addressed subject to the two constraints namely clash constraint and wavelength continuity constraint. According to clash constraint, two light-paths sharing a common link have to occupy distinct wavelengths; otherwise, the transmitted signals would interfere with each other. Moreover, wavelength continuity constraint implies that each light-path has to occupy an identical wavelength channel on its entire route from source to destination. Wavelength continuity constraint can be released if we get use of wavelength converters. However, we note that the wavelength converters are still in their infancy. These devices are rarely used due to excessive cost and power consumption.

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RWA in WDM core networks, generally, deals with two kinds of traffic namely static traffic and dynamic traffic. In static traffic, a set of requests with infinite holding times are known in advance. The objective is to establish the entire request set on the given network topology, using minimum number of wavelength channels (i.e. network resources). On the other hand, if the number of idle wavelength channels is limited, then the objective is to maximize the number of successfully established requests. RWA when solved for static traffic case is called static RWA which is approached various techniques, e.g., optimization approaches, evolutionary algorithms and heuristics.

In order to achieve the optimal answer, optimization problems with various objective functions are developed. Most of them fall in the category of integer linear programming (ILP) problems [2,3]. Optimization approaches usually try to yield the optimum answer; however, they are not applicable for large size problems (i.e., large size network topologies with large number of requests); therefore, in order to address such problems, the evolutionary algorithms such as genetic and bee colony algorithms, among others, have become popular. Unlike optimization approaches, the evolutionary algorithms are able to achieve satisfactory results for problems with linear/nonlinear objective functions. Various modifications of evolutionary algorithms known as meta-heuristics are proposed to solve the RWA problem [4,5]. Nevertheless, meta-heuristics have three major drawbacks that might restrict the use of such algorithms: (i) they may trap in local optima, (ii) the number of iterations in order to achieve satisfactory solution might be too large, thus resulting in excessive running time; and (iii) performance of such algorithms highly depends on the algorithm parameters which have to be carefully adjusted and updated for different problems. Finally, heuristics which are known to be the most practical approaches to solve the RWA problem, achieve satisfactory results (not necessarily the optimum answer) within an acceptable time and complexity, such as [6–9] among others, thereby, these algorithms have lately gained significant attention by researchers. The approach presented in [6] decomposes the RWA problem into two subproblems, the routing subproblem and the wavelength assignment subproblem. Authors in [7] have developed simple and efficient heuristic algorithms for RWA problem by applying classical bin packing algorithms. Despite the efficiency of the algorithms proposed in [7], the associated running time is high. In order to address the aforementioned issue, authors in [8] have proposed efficient implementation of these algorithms. Tackling the static RWA problem with main focus on reducing total number of required wavelength channels is the subject of [9], however, we noted that the approach used in the paper is not applicable for dynamic traffic.

In [10,11], the static RWA problem is represented mathematically using quadratic programming model, followed by proposing an efficient heuristic to obtain a satisfactory answer. It is verified that creation of bottleneck links is avoided when the quadratic model is applied.

On the other hand, under dynamic traffic case, requests arrive randomly in time instants and each request is associated with a random holding time. In core networks, request arrivals are assumed to follow the Poisson process while the corresponding holding times exponentially distribution [12]. Dynamic RWA problem, sometimes referred to as online RWA, is generally solved via decoupling the problem into two sub-problems: routing sub-problem and wavelength assignment (WA) sub-problem [13–15]. Routing sub-problem is usually solved using shortest-path algorithm while the simple and efficient first fit (FF) algorithm is known to be a common method to obtain acceptable results for the WA sub-problem. The most efficient online provisioning approach, which is referred to as shortest path routing and wavelength assignment algorithm (SP-RWA) henceforth, is to route the requests upon their arrivals, using the shortest-path algorithm followed by the FF wavelength assignment scheme. The main objective in dynamic RWA solutions is to establish the incoming requests in such a way that the blocking probability for upcoming calls or simply the blocking rate becomes minimum. Since the calculations are performed online, time complexity becomes an important issue in designing dynamic RWA algorithms. Hence, we are interested in dynamic (or online) RWA algorithms which yield satisfactory results within acceptable running time and complexity.

We note that an optical signal quality may seriously degrade due to impact of physical layer impairments, while traversing multiple intermediate nodes and links. As a consequent, the bit error rate (BER) of the received signal might increase which might lead to situation where the received signal becomes useless. Thus, signal quality has also to be taken into account in establishing the light-paths. The mentioned procedure is carried out in the impairment aware RWA (IA-RWA) algorithms, which are responsible to perform a cross layer optimization approach between the physical layer and the network layer to provide an acceptable level of quality of transmission (QoT). An interested reader is referred to [16] where an illustrative review on dynamic IA-RWA algorithms has been provided. Note that when light-paths are packed on certain links, the impact of non-linear impairments become dominant, thereby, the light-paths become prone to higher BER. Therefore, balancing the load over the whole network links will not only reduce the creation of bottleneck link, but also will have further impact on improving the system performance in terms of BER (i.e., QoS).

Fault management is also known as a challenge in WDM-based optical networks where failures might occur due to fiber cuts. Bundles of fibers are prone to getting cut because of construction or destructive events, such as earthquakes. Therefore, fault management or survivability is also taken into consideration while dealing with the RWA problem. The common approach is to assign two link disjoint paths to each request namely primary path and backup path with main focus on minimizing total number of used wavelengths on all the links of the network. Authors of [17] have addressed the RWA problem with path protection by means of proposing off-line algorithms for static traffic struggle with single-link failure. Traffic grooming adds another dimension to RWA problem by introducing opportunities to further enhance the development of optical transport networks by means of efficiently multiplexing low bit-rate traffic into high bit-rate stream. In [18], the ant colony optimization algorithm which is a meta-heuristic approach, has been implemented to solve

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