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An improved scheduled traffic model utilizing bandwidth splitting in elastic optical networks

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ABSTRACT

The surge of traffic in today's networks gave birth to elastic optical networking paradigm. In this paper, first we propose to use the scheduled traffic model (STM) in elastic optical networks (EONs) to ensure guaranteed availability of resources to demands which enter into the network with a predetermined start and end times. In optical networks, such demands are referred to as scheduled lightpath demands (SLDs). To increase the amount of bandwidth accepted in network, next we introduce a time aware routing and spectrum assignment (TA-RSA) approach. We observed that provisioning of bulky SLDs has become more challenging in EONs due to enforcement of RSA constraints. To address this challenge, we improve the proposed STM and designed three heuristics for its implementation in EONs. In this work, we collectively refer to these heuristics as bandwidth segmented RSA (BSRSA). The improved STM (iSTM) allows splitting of SLDs in bandwidth dimension by utilizing the knowledge of attributes viz. demand holding time, overlapping in time and bandwidth requested by SLDs. Our numerical results show that BSRSA consistently outperformed over TA-RSA under all distinctive experimental cases that we considered and achieved fairness in serving heterogeneous bandwidth SLDs. The impact of splitting on the number and capacity of transponders at nodes is also gauged. It is observed that ingenious splitting of demands increases the number of resources (on links and nodes) used, and their utilization, leading to an increase in bandwidth accepted in the network.

1. Introduction

With the exponential growth of traffic, optical networks are experiencing a paradigm shift. This growth is fueled by various bandwidth hungry applications such as e-science, grid computing, collaborative learning through audio-visual aids, etc. and it will soon cross the zettabyte threshold [1]. Recently, the elastic optical networks (EONs) have emerged as a promising paradigm to accommodate this torrent of traffic with a high spectral efficiency [2]. EONs employ a flexible grid which divides complete optical spectrum into a number of smaller units known as frequency slots (FSs). To provision a connection request (CR), the problem of searching a route and allocating desired number of FSs on each link of the route is called as routing and spectrum assignment (RSA) in EONs [3]. The solution to the RSA problem must follow two constraints, namely, spectrum continuity and contiguity. The spectrum continuity constraint states that a lightpath must use the same indexed slots on each traversed link; however, the contiguity constraint requires that slots assigned to a demand must be consecutive in the spectrum. Authors in [4] discussed various aspects of RSA problem in detail.

In today's bandwidth competitive environment, the objective of network operators has become threefold: accepting a huge volume of bandwidth in the network, efficient utilization of available resources and achieving significant gain in revenue with a high degree of customer satisfaction. Moreover, customers demand a guaranteed availability of resources when a CR arrives in the network. In EONs, allocating resources to a CR immediately when it arrives in network seems an obvious choice to operators for designing their network. This is referred to as dynamic provisioning of resources [5]. However, in its original form this technique cannot promise guaranteed availability because of the frequently changing load conditions on links. For example, consider a scenario where a virtual classroom is setup for one year course. The lectures are scheduled everyday from 10:00 to 14:00 h which is the guaranteed availability period for this application. If the operator is relying on dynamic provisioning then it has to setup this connection everyday at 10:00 h when CR arrives in the network and release it at 14:00 h. Now suppose someday, the requested bandwidth is not available due to heavy load in the network at 10:00 h and

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operator have to block the CR. This leads to poor customer satisfaction and a significant loss of revenue to the operator.

The solution to this problem is to use scheduled traffic model (STM) [6]. STM is a promising model to be used in the provisioning of CRs for which the start and end times along with their bandwidth requirement are known ahead of time. Such CRs are referred to as scheduled lightpath demands (SLDs) [7]. These demands are scheduled on the basis of prior information about their setup and tear down times. However, a great deal of work has been reported in literature considering STM, in reference to conventional fixed-grid optical networks [6–12]; to the best of our knowledge, this model has not yet been implemented in EONs.

In this paper, we propose to use STM in EONs for the provisioning of SLDs. Due to the use of flexible grid, EONs can easily accommodate demands having heterogeneous bandwidth requirement. However, in addition to the inherent knowledge of bandwidth requested by various demands, we wish to leverage the knowledge of time dimension of SLDs in EONs to achieve significant gain in terms of the amount of bandwidth accepted.

Initially, we present a time-aware RSA (TA-RSA) mechanism incorporating STM to EONs. TA-RSA takes into account the time-disjointness property of SLDs while performing RSA. We then compare the performance of TA-RSA with the traditional RSA approach used in EONs. We refer to this traditional RSA approach as time-unaware RSA (TU-RSA). Though TA-RSA outperformed TU-RSA by accepting a significantly large amount of bandwidth in the network, provisioning bulky SLDs in EONs is more challenging than it was in fixed-grid optical networks due to the enforcement of RSA constraints such as spectrum continuity and contiguity.

To address this challenge, we improve STM such that the effect of these RSA constraints is minimized and the time dimension of STM is efficiently utilized. In the improved STM (iSTM), SLDs are split in bandwidth dimension. To perform splitting, iSTM utilize the knowledge of bandwidth and time dimensions. In order to implement the iSTM, we propose three heuristics. We refer to these three heuristics collectively as bandwidth segmented RSA (BSRSA) strategy. We use the sliceable bandwidth variable transponder (SBVT) model proposed in [13] to divide the bandwidth of a demand into a number of chunks. We refer to these chunks as flows in this work. It has been observed that splitting the demands which require huge amount of bandwidth and have longer holding time (i.e., the duration for which a SLD remains active in network) is beneficial to increase throughput of the network. Simulation results demonstrate that proposed heuristics achieve fairness in serving demands with heterogeneous bandwidth and time requirements. The effect of proposed heuristics on the capacity and number of transponders utilized is also investigated.

The remainder of this paper is structured as follows: a brief review on STM, and the techniques used for decomposition of demands are presented in Section 2. Section 3 presents the formulations pertaining to the provisioning of SLDs along with the proposed heuristics. In Section 4, the numerical simulation setup and results are reported. Finally, Section 5 concludes the paper.

2. Related work

STM was proposed by authors in [7]. Demands under STM overlap in time. This gives the operator a freedom to assign same resources to other demands which are disjoint in time. This is known as time disjointness property of SLDs. In literature this property has been used to achieve various objectives in the fixed-grid optical networks.

Authors in [8–10] used the time disjointness property to minimize the required number of network resources; however authors in [11] utilized this property to minimize congestion in the network. In [12] authors exploited the time disjointness of SLDs to maximize the number of demands established. Since STM is a traffic matrix based model, i.e., the complete set of SLDs is known a priori, SLDs can be ordered before the provisioning to yield good results [6].

In the present work, under the iSTM, SLDs are decomposed with respect to their requested bandwidth into sub-parts. In [14], authors suggested the use of control plane for the splitting of demands. Once the splitting of a demand is done, each sub-part of the demand is assigned a bandwidth variable transponder (BVT) that is idle in the low load scenario. In this approach, decision of splitting requires prior knowledge of the available resources.

A split-spectrum enabled RSA (SSRSA) approach has been discussed in [15] for the SS-enabled EON. The aim of this provisioning approach is to minimize the splitting of demands and the spectrum fragmentation. SSRSA used single path to route all the parts of a demand which increased the blocking of connections. In [16], authors solved this problem under SS-enabled EONs by considering modulation format and multipath routing. Under the assumptions considered in the work, authors suggested the use of BVT based implementation, as it appeared more cost effective. However, contrary to this, authors in [17] demonstrated that with respect to the total transponder cost, SBVTs [13] are three times cost effective than BVTs. In the light of the fact that the capacity of SBVTs can be efficiently utilized as they can serve multiple lightpaths belonging to different s-d pairs in parallel and the cost analysis presented in [17–19], we prefer to use SBVTs over BVTs in this work for the purpose of splitting the flow belonging to a demand into multiple flows.

In addition to these proposals, authors in [20] have categorized the BVTs on the basis of their slicablility feature as: non-slicable BVT, fully sliceable BVT, and partially sliceable BVT. The non-slicable BVT is the basic BVT equipped with grooming capability to improve the transponder utilization. With the help of simulation results, authors demonstrated that significant power savings can be achieved using SBVTs at the cost of more power consumption by amplifiers due to the increased number of guard bands during slicing. In [21] authors proposed a heuristic to perform RSA using multi-wavelength SBVT. Their simulation experiments demonstrated the effectiveness of the scheme on the metric of blocking probability.

3. Provisioning scheduled lightpath demands

In this section, the nomenclature used in algorithms for provisioning of SLDs is presented. Furthermore, we define several constraints and design metrics used in the performance evaluation of proposed BSRSA. The subsections cover detailed discussion on the proposed heuristics.

We consider the physical network topology $G(N, L, F)$ representing EON, where N is the set of nodes, L is the set of links, and F is the set of FSs on each fiber link $l \in L$. A set of SLDs $R(s, d, B, \alpha, \beta)$ where s represents the source node, d represents the destination node and $(s, d) \in N$, B represents the bandwidth (in Gbps) requested by SLDs, α and β represent the setup time and tear down time of a SLD, respectively such that $\beta \geqslant \alpha$. We assume that the time is slotted. The set of time slots is indicated by T such that each slot is one hour long in time (i.e., $|T| = 24$). The set of candidate paths for each SLD present in R is represented by K. To perform RSA for each SLD, k candidate paths are pre-computed. Since BSRSA allows multiple flows belonging to a demand to be routed through different paths, a boolean variable MP_r is set to 1, if $r \in R$ requires multipath routing, otherwise 0.