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Computing approximate blocking probability of inverse multiplexing and sub-band conversion in the flexible-grid optical networks

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ABSTRACT

With the rapid growth of data rate, the optical network is evolving from fixed-grid to flexible-grid to provide spectrum-efficient and scalable transport of 100 Gb/s services and beyond. Also, the deployment of wavelength converter in the existing network can increase the flexibility of routing and wavelength allocation (RWA) and improve blocking performance of the optical networks. In this paper, we present a methodology for computing approximate blocking probabilities of the provision of multiclass services in the flexible-grid optical networks with sub-band spectrum conversion and inverse multiplexing respectively. Numerical calculation results based on the model are compared to the simulation results for the different cases. It is shown that the calculation results match well with the simulation results for the flexible-grid optical networks at different scenarios.

1. Introduction

With the exponential growth of communication traffic and increasing of service types, it is essential to realize the improvement of spectrum efficiency and network capacity. Many research efforts are now focusing on the technologies beyond 100 Gb/s, which include single-carrier [1], multi-carrier techniques [2] and high level modulation formats. Multi-carrier approaches can promise large aggregate capacity and high spectrum efficiency to support 1Tb/s super-channel transmission for the future optical networks. For the traditional fixed-grid WDM networks, the channel grid is fixed and the requirement of flexible wavelength cannot be satisfied. Because of its rigid grid and coarse bandwidth granularity, the networks require full allocation of the channel grid to a connection, even when the traffic demand is insufficient to fill the entire capacity of one fixed-grid, which leads to the waste of optical spectrum severely. In parallel with high speed data rate, flexible grid is important to improve the spectrum efficiency of networks, which suggests for a fine granularity so as to be capable of providing the required capacity to the sub- and super-channel demands adaptively [3]. The flexible-grid technology divides the optical spectrum into multiple equally-sized frequency slices, where a variable number of consecutive slices (frequency slots) can be allocated to each connection depending on the requested bandwidth and the modulation format. ITU-T G.694.1 document describes a new optical spectrum management specification for flexible-grid DWDM optical networks, in which 12.5 GHz becomes a fine spectrum slot and channel spectrum is flexibly allocated in integer multiples of its spectrum granularity based on channel capacity.

The problem of routing and wavelength allocation (RWA) has been researched extensively to improve the blocking performance of WDM optical networks and the related analytical models based on the classical Erlang Multirate Loss Model have also been built [4,5], which are only fit for the single-carrier optical networks. The layer graph model based on wavelength decomposition has been studied for computing blocking probability [6], which has fairly high computational complexity. In [7], the authors have proposed an analytical model for the flexible grid optical network, which take the spectrum contiguity constraint into consideration. The spectrum contiguity constraint means that the frequency slots on a link occupied by one optical channel must be contiguous. However, the contiguous spectrum need not be requested for the analytical model in our manuscript. In [8], the reduced load approximate approach was proposed for state-dependent routing with multi-rate traffic. And in [9], the approach was developed to consider the fixed routing (FR), least loaded routing (LLR), and fixed alternate routing (FAR) routing and wavelength assignment policies and the analytical model of the multi-carriers assignment strategy was proposed. The authors considered three data-rates under unequal arrival ratio. In some sense, the paper considered the traffics in WDM network, but in this paper, we will consider the elastic optical network and take distance-adaptive modulation

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into consideration. In addition, as we all know, the employment of wavelength converter in existing fixed-grid network can increase the flexibility of the RWA and improve the blocking performance of the optical networks [10]. In paper [11,12], the authors demonstrated the scheme of inverse multiplexing based on superchannel multicasting to separate the superchannel into multiple small discontinuous spectrum slots. In paper [13,14], the authors presented the simulations of sub-band spectrum conversion and multi-path routing, and verified the advantage in blocking performance of sub-band spectrum conversion and the efficiency in spectrum utilization. But so far, the analytical approaches for inverse multiplexing and sub-band spectrum conversion have not been presented. So, in this paper, we mainly setup the analytical model for inverse multiplexing and sub-band conversion for the mixed data-rate in the equal arrival ratio. The sub-band spectrum conversion and inverse multiplexing are the technique of solving spectrum defragmentation for elastic optical networks. There has been significant amount of work on spectrum defragmentation for elastic optical network. In [15], the authors proposed a technique which allows to move the spectrum of the connection without interrupting services of any existing connections by combination of the fast tuning speed of superstructure grating distributed Bragg reflector (SSG-DBR) lasers, the blanking of the optical emission from the SSG-DBR laser during the tuning, and the buffering of the bits during the tuning. And in [16], the authors show several spectrum defragmentation methods, such as re-optimization technique and make-before-break (MbB) approach. The former aims at compacting the assigned slots so as to consolidate the available spectrum significantly and increase the possibility to allocate new connections. The MbB approach exploits the rerouting solution to do spectrum defragmentation. This technique finds an available alternative pair of route and slot set for each blocked path demand and requires an additional transmitter to provide an extra connection. For the sub-band spectrum conversion we proposed in this paper, the service demand searches for spare spectrum and if the spare spectrum is less than the spectrum requirement, the spare spectrum is first occupied for the part of the superchannel and then looking for other spare spectrum for the conflicted part. The service requests can be classified by the demanded number of wavelengths. The analysis model for fixed-grid has been proposed in [4,5], so we don't discuss a lot in this paper. In this paper, based on the previous works, we present an approximate method to compute the blocking probability for sub-band spectrum conversion and inverse multiplexing of the flexible-grid optical networks.

The rest of the paper is organized as follows. In Section 2, we illustrate the spectrum allocation of sub-band spectrum and inverse multiplexing. And then, some assumptions and an approximate method for the calculation of the blocking probability are presented in Section 3. The network topology and the analytical and simulation results for sub-band spectrum conversion and inverse multiplexing are shown in Section 4. Finally, the conclusions are given out in Section 5.

2. Illustration of network architecture

Fig. 1 shows the schematic diagram of the sub-band spectrum conversion. When the enough allocation of the same spectrum on each link in the routes of a lightpath is unavailable, the available spectrum is first occupied, then, looking for enough spectrum for the remaining part. In this case, the spectrum continuity constraint can be ignored. When the overlapping spectrum on each link has found the spectrum slots, the traffic is established. If there is no remaining spare spectrum on any links, the request will be dropped. The physical implement has been demonstrated in [17].

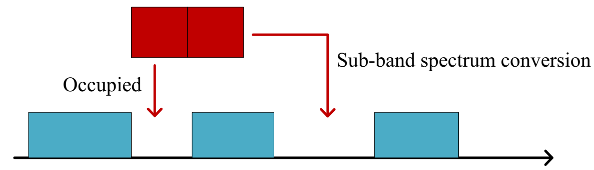

Fig. 1. Channel allocation of sub-band spectrum conversion.

Wavelength selective switch (WSS), as the core switching element of the reconfigurable optical add/drop multiplexer (ROADM), is capable of supporting flexible channel allocation. And wavelength conversion is used to change the spectrum allocation for the conflicted part of the superchannel when the full spectrum is not available on each link in the routes of a lightpath. Inverse multiplexing is built on elastic transmission with the additional capability of separating the superchannel into multiple small discontinuous channels at the same path, while the spectrum is not available for the whole superchannel. The same spectrum slots must be allocated for each link in the routes of a lightpath. For the both scenarios, once any of the small spectrum slots is not found, the request will be dropped. Both of them split the superchannel into multiple spectrum slots, but the inverse multiplexing requires the same spectrum slots on each link in the routes and the sub-band spectrum conversion is not subject to this constraint.

3. Assumptions and analytical model

In order to present our analytical model, some assumptions and notions are given here. The fixed routing policy is considered, assuming that there is only one route between any origin and destination (OD) pair$_o$. When a call with the requirement of b wavelengths arrives on OD pair$_o$, the request will be set up only if there is sufficient number of idle wavelengths to satisfy the requirement. Otherwise, the call will be rejected. And we classify the service requests with the different demanded number of wavelengths. The related notions and definitions of the model are as follows.

- a_o^s: the arrival rate of class s of the lightpath request on OD pair $_o$.
- $1/\mu^s$: the average holding time of the lightpath; for simplicity, we set the average holding time as unity (i.e., $1/\mu^s = 1$).
- b^s: the required number of wavelengths of the lightpath request of class s.
- $a_j^s(m_j)$: the call setup rate of class s on link j with m_j idle wavelengths.
- W: the wavelength capacity on each link.
- X_j: a random variable denoting the number of idle wavelengths on link j.
- $q_j(m_j) = Pr[X_j = m_j](m_j = 0, \ldots, W$: the probability distribution for m_j idle wavelengths on link j.
- L_o^s: the lightpath blocking probability of class s on OD pair$_o$.
- P_B: the average lightpath blocking probability of the whole network.

In this paper, we consider two scenarios: sub-band spectrum conversion and inverse multiplexing. In the latter case, for the wavelength continuity constraint, we consider the following conditional probability. Here, we assume that route r has constituent links $\{j_1, j_2, \ldots, j_{h(r)}\}$ ($h(r)$ is the number of the links on route r).