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Blocking performance approximation in flexi-grid networks ☆

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ABSTRACT

The blocking probability to the path requests is an important issue in flexible bandwidth optical communications. In this paper, we propose a blocking probability approximation method of path requests in flexi-grid networks. It models the bundled neighboring carrier allocation with a group of birth–death processes and provides a theoretical analysis to the blocking probability under variable bandwidth traffic. The numerical results show the effect of traffic parameters to the blocking probability of path requests. We use the first fit algorithm in network nodes to allocate neighboring carriers to path requests in simulations, and verify approximation results.

1. Introduction

Some current and the coming network applications/services require communication network infrastructure to provide large link capacity to end users. Besides large transmission capacity requirement, most high-rate applications/services anticipate network service providers to provide bandwidth on-demand (BoD) service, but not constant bandwidth. From the point view of the network service providers, they wish to serve as much customers as possible within the current network infrastructure. To achieve this, BoD service is a good candidate. Recently, one sort of network called Globally Reconfigurable Intelligent Photonic Network (GRIPhoN) [1] is put forwarded by researchers. The network is reported to have the dynamic bandwidth allocation function, which may be deployed by the network service providers in the future.

The dynamic bandwidth allocation can provide relatively short-lived connection requirements quickly, especially parts of connection attributes are informed. Take the replication procedure among data centers as an example: as soon as it is needed, the cloud service informs the network the required attributes, i.e. the start time, the holding times and bandwidth requirement. The network then dynamically allocates network resources (light paths etc.) to this connection at the time and releases them after the service is finished.

Orthogonal frequency-division multiplexing (OFDM) is a multiplexing technique encoding digital data on multiple carrier frequencies, which has been widely applied in wire and wireless communications. Recently it is found to be a potential technology that can be used in optical communications [2,3]. The optical OFDM multiplexing techniques, including direct detection optical OFDM (DDO-OFDM) and coherent optical OFDM (CO-OFDM), have the ability of mini-grid or gridless wavelength allocation in optical fibers [4], and can apply different modulation levels for different light paths [5].

Accordingly, OFDM optical transport network can accommodate BoD requirement. The optical wavelength conversion device, which converts conveniently the wavelength of a light to another, are quickly developed in recent years, i.e. the new reconfigurable optical add-drop multiplexer architecture embedded wavelength selective switches or tunable wavelength blockers [6,7]. Furthermore, all-optical wavelength converter is also switchable [8]. In such networks, the set of adjacent carriers used by a traffic flow in a link may differ from those in other links on the path. For example, if the path of a traffic flow includes links l_i and l_j. Link l_i allocates two carriers with central frequency f_m and f_{m+1} to the traffic flow, while link l_j may allocate two carriers with central frequency f_n and f_{n+1}, where $n \neq m$.

The blocking performance in dynamic flexible grid networks that support flexible bandwidth allocation is evaluated in a simulation way [6,9]. A lot of model are build up to have the blocking probability approximation in loss networks, such as [10–12]. In [13], the group data of arrivals is modeled. In [14,15], the authors consider several spectrum expansion/contraction for modifying the spectrum with routing schemes, and investigate the blocking probability under the policies. A similar network is called elastic

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optical network (EON), which is recently focused on by the researchers. Shi et al. show the effect of bandwidth fragmentation on the blocking probability of EONs by a simplified operation model [16]. An iterative procedure is applied to estimate the blocking performance in CO-OFDM networks [17]. The blocking probability in different operation scenarios, with or without contiguous spectrum assignment (CSA) constraint, in EONs are investigated [18]. The authors in [19] provide an exact performance analytical model and two heuristic algorithms in the spectrum allocation system and flexible grid optical links. In [20], the complexity of scheduling resources for jobs in an adjacent manner are investigated.

In this work, we estimate the blocking probability in flexi-grid networks with dynamic wavelength or spectrum assignment. The critical problem is that a request should be served by neighboring carriers, not by multiple discontiguous carriers. This scenario is similar to the WCSA-FF scenario in [18]. However, the approximation method in [18] adopts the APP.1 method (or Kaufmans method), which is for the problem that the resources are not necessarily contiguous [21]. We can find that the Kaufmans method is not with the contiguous resource allocation constraint. The approximation method here is to have the blocking probability approximation with strict contiguous resources allocation constraint. The key, in our estimation, is to bundle the suitable count of neighboring carriers as a server. The detail description about this is in Section 2. In Section 3, we obtain numerical results in some scenarios. In simulations, we adopt the first fit algorithm to distributively allocate the neighboring carriers in each node to the coming requests. The first fit algorithm is not the best one, but the popular one when verifying the analytical results. In Section 4, we compare the numerical results with the simulation ones.

2. Approximation of the blocking probability

In the flexi-grid network, one carrier is the basic spectral granularity. The overlapping orthogonally modulated adjacent carriers is used to serve a traffic flow. For a traffic flow requiring the bandwidth more than a carrier can carry, the traffic should be allocated multiple adjacent carriers. Furthermore, a newly arriving traffic request can be dynamically assigned in each trunk on a path, which forces the network flexibility. In the context of a flexi-grid network, digital data is encoded on a single carrier frequency if the amount of the data is small enough, or else on multiple carrier frequencies. These carriers should be neighboring and be bundled to serve a connection. Full wavelength conversion circuit switching is enabled in each node, with which the traffic from any channel on one trunk can be switched to any other channel on an adjacent trunk.

For the sake of convenience, the main notations are listed in Table 1.

Table 1
Notations.

Notation	Meaning
m_l	The modulation level in link l
c_l	The channel number in link l
A_{lj}	The routing matrix
$b_w^j(t)$	The bandwidth request at time t in connection j
$B_{wl}^j(t)$	The bundle size at time t in link l, connection j
B	The expectation of bundle size
K	The carrier number in the initial state
b_w	The expectation of the bandwidth request
G	The traffic load
g_b	The guardband number
C	The link capacity

2.1. Network model

Consider a flexi-grid network with L links and N nodes. Each link $l, l \in \{1, 2, \cdots, L\}$ contains a trunk with s_l channels. The link l is comprised of f_l fibers, and each support c_l carriers. The result is that link l has $s_l = f_l c_l$ channels. Suppose the network is with J connections and R paths. One traffic flow over one connection takes one path. A path can be identified with a subset of the set of links $\{1, 2, \cdots, L\}$, which means $r = \{l : A_{lr} = 1\}$. A connection between a SD pair is also comprised of several links, where the traffic is transferred. If the traffic on connection $j, j \in \{1, 2, \cdots, J\}$, uses only one path $r, r \in \{1, 2, \cdots, R\}$, it is called fixed path routing. In this case, if path r uses link l, let $A_{lr} = 1$, or else $A_{lr} = 0$. If the traffic on connection j can use another path $r' \neq r, r' \in \{1, 2, \cdots, R\}$, it is called fixed alternate path routing. If the connection j uses link l, let $D_{lj} = 1$, or else $D_{lj} = 0$. In the case of fixed path routing, it has $A_{lr} = D_{lj}$. In the case of fixed alternate path routing, the traffic on connection j can use alternate path r'. In this case, it has $A_{lr'} = D_{lj}$ when the traffic is on the alternative path. To avoid interference, the set of adjacent carriers used by a traffic flow may be separated from the set of adjacent carriers used by other traffic flows. The carriers between them correspond to guard bands. The number of the guard carriers is denoted as g_b.

The capacity provided by a carrier is also related to the modulation level. The modulation level in each carrier can arbitrarily or alternatively be different, by BPSK, QPSK, 8QAM, etc. techniques. The capacity provided by a carrier using BPSK, c [Gb/s], is the basic capacity. The capacity provided by a carrier using QPSK or 8QAM corresponds to twice or triple of the basic capacity, respectively. If denote the modulation ←level multiplier as $m_i, i \in [1, M]$, the capacity of a channel is m_{ic} [Gb/s], and the capacity of one trunk, denoted as C_l, is $C_l = \sum c_l = \sum m_i c$ [Gb/s].

The data from upper layer of the network are groomed to be traffic requests [22–24]. The bandwidth of a traffic flow is time dependent, and not constant. That is, the bandwidth request of a traffic flow in an interval may differ from that in another interval. In the context of the interval, it may be one minute short or one day long. Because the request traffic is uncertain, it is reasonable to regard the request stochastic. Thus each bandwidth request of a traffic flow includes two basic properties, the arrival time (AT) request and the holding time (HT) request. Suppose AT and HT of the requests are continuous time stationary stochastic processes. The probability distributions of them are dependent of the actual data, and they are modeled to be Possion process here. Besides the above two properties, one traffic flow has another property called the bandwidth request (BR). The bandwidth request is also a continuous time stationary stochastic process and its probability distribution can be anything. Typically, here, BR is treated to be a process with an uniform distribution.

As an example, the procedure how one traffic flow is formed is shown in Fig. 1. The bandwidth requests is denoted as BR1, BR2, $\cdots$, BRi, $\cdots$. BR1, requiring bandwidth B_{w1}, arrives at time t_{A1} and cancels the requirement at time $t_{A1} + t_{s1}$. After BR1 arrives, BR2 arrives at time t_{A2} and stops the requirement at time $t_{A2} + t_{s2}$. In the same way, BRi, requiring bandwidth B_{wi}, arrives at time t_{Ai} and cancels the requirement at time $t_{Ai} + t_{si}$. It can be seen that $0 < t_{A1} < t_{A2} < \cdots < t_{Ai} < t_{A(i+1)} \cdots$, because the bandwidth requests arrive one by one. The arrival interval $t_{ai} = t_{Ai} - t_{A(i-1)}$ is viewed as a stochastic variable. The holding time t_{si} is also a stochastic variable. There exists the case where a BR is still requiring bandwidth when the following BR arrives. In this case, the bandwidth required will be superposed. For example, in Fig. 1, BR3 arrives before BR2 leaves, i.e., $t_{A3} < t_{A2} + t_{S2}$. The requiring bandwidth is the sum of BR2 and BR3 in the interval