Effective Utilization of Transponder in Elastic CD-ROADM Optical Networks with Traffic Grooming

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***Abstract*—As internet traffic continues to grow in volume and diversity, it is important and challenging to exploit the full potential of the flexibility of the ROADMs. In this study, we propose a traffic grooming strategy with virtual auxiliary graph to optimize the configuration of CD-ROADMs, while considering both of the inter-node spectrum contention and the intra-node TP contention in flex-grid optical networks.**

Keywords—Elastic optical networks; Internal blocking; traffic grooming; CD-ROADM;

I. Introduction

High-capacity transparent optical networks are needed to accommodate the rapid growing IP traffic. To improve spectrum efficiency, the flex-grid or elastic optical networks (EONs) are the foreseen near-future evolution of transparent optical networks [1]. In EON, a specified amount of spectrum slots in each traversed link is allocated on-demand to each connection. And, at each traversed node, colorless, directionless, contentionless, reconfigurable optical add-drop multiplexer (CDC-ROADM) are provisioned for optically switching lightpaths. Fig. 1 shows a typical CDC-ROADM structure. However, the hardware cost to realize pure CDC features is rather high even when the nodal degree is relatively small. It is because the high port count wavelength selective switches (WSSs) as well as a large number of transponders (TPs), which account for about 80% of the total node cost [2]. Moreover, a connection's requested bandwidth can be much lower than the TP capacity. Hence, provisioning each connection by a separate lightpath leads to low utilization of high-capacity TPs and high spectrum wastage by guard bands.

The authors in [3-4] just investigate the impact of various traffic grooming (TG) policies on the spectrum utilization in EONs by saving the usage of guard bands. However, these policies have not focused on the improvement of the TP utilization with the assumption that intra-node contention in ROADM node. Generally, planning a flex-grid optical network is typically performed by elastically allocating spectrum slots as a need basis to the lightpath demands, while satisfying the spectrum continuity and non-overlapping assignment constraints. The problem is typically referred to as the Routing and Spectrum Allocation (RSA). Such lightpath demand between a source-destination pair can be blocked in the three possible reasons: 1) network-level inter-node blocking, when there is no route to be found satisfying the above two constraints; 2) TP blocking, when no free TP is available ether at source or destination node; 3) intra-node contention is due to the limited number of TP-banks. The latter two reasons is related with the TP configuration in the ROADM node, which greatly contributes to the ROADM hardware node.

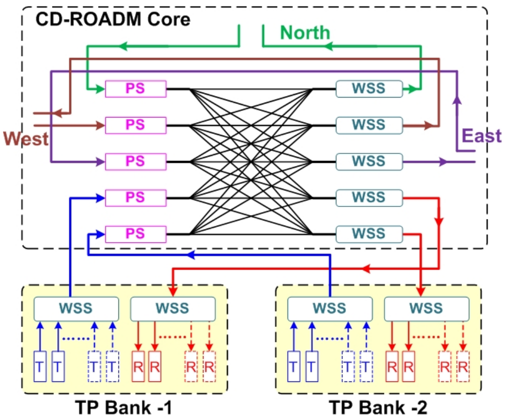

Fig. 1. A typical CDC-ROADM structure.

In this paper, we are interested in evaluating the minimum of the TP-banks and the minimum of TPs in each TP-bank required in DCDG-ROADMs, in order to eliminate totally TP blocking and intra-node contention in practice. With the cost-effective TP configuration, a lightpath demand can only suffer from network-level inter-node blocking. This study targets to tradeoff TP configuration cost for the acceptable network performance in the future elastic optical networks.

II. Dynamic Traffic Model

In the dynamic traffic model, connection requests arrive one at a time and hold for certain durations. The problem of dynamic lightpath traffic in elastic optical networks can be stated as follows: The network topology is represented by a graph $G^s(N^s, L^s)$, where N^s is a set of network nodes with the capability of TG and L^s is a set of bidirectional links (with two unidirectional fibers). A slot network is assumed with grid granularity g and the total number of slots supported in each fiber is represented by T. B is the number of slots consumed by a guard band. In the CD-ROADM, we assume that the transmission capacity of TPs is A, and number of TP-banks in a node is C. Notice that a specific wavelength can be added/ dropped only once in a TP-bank, which is so-called intra-node wavelength contention. A connection request is represented by $r(s, d, b)$, where s and d are the connection's source and destination, and b is the requested bandwidth in terms of number of mini-grids. When a connection request r arrives, the control plane determines

TABLE I. Notations used in this study.

N	set of nodes in an optical network
L	set of fiber links in an optical network
s	destination of a connection request
d	destination of a connection request
b	requested bandwidth of a connection request
B	number of slots consumed by a guard band
T	total number of slots in each fiber
A	transmission capacity of TPs
M	maximum allowed number of reserved slots
E	An existing lightpath
R	number of reserved slots in an existing lightpath
R_f	number of free reserved slots in an existing lightpath
C	number of TP banks in a node

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how to provision it immediately: how to route r through existing lightpaths (electrical-layer routing), or how to establish new lightpaths by optical-layer RSA. Below, we show how the electrical-layer routing and optical-layer RSA can be jointly solved by an virtual auxiliary graph (VAG). The notations used in this study are listed in Table I.

III. TRAFFIC GROOMING STATEGY

A. Virtual Auxiliary Graph

In this study, in order to increase TP utilization and optimize the configuration of the ROADMs, we propose a VAG $G^v(N^v, L^v)$. The VAG converts all the established lightpaths, with free reserved spectrum resources, into a single graph. A VAG is constructed each time a new lightpath is established or a connection completes. All the new set of virtual nodes N^v represent the nodes in physical network in the network topology, and all the virtual links L^v in the VAG correspond to an existing lightpath between the node pairs in the physical network. These lightpaths are able to accommodate the new connection request by allocating more subcarriers. To build a VAG, we first update the number of free reserved slot R_f of each established lightpaths *E* in the optical network. Then, for any source and destiny node pairs (*s*, *d*), we convert the lightpath *E*, having the maximum R_f, into a link from s^v to d^v in the VAG. Due to the consecutive constraint, each link in the VAG must have at least $b+B+R$ consecutive unused slots to establish a new lightpath. Therefore, if the maximum R_f in one virtual link $l^v \in L^v$ is less than $b+B+R$, this virtual link l^v will be removed from the VAG. Finally, all these new set of virtual nodes N^v and virtual links L^v constitute a new VAG.

An example VAG established for a new connection request from node A to C is shown in Fig. 2(b). Before the connection is provisioned, there are three existing lightpaths in the optical network is shown in Fig. 2(a): the route of lightpath L1 is A→B→D, and it reserved 4 slots; the route of lightpath L2 is from A→B→D, and it reserved 2 slots; the route of lightpath L3 D→C, and it reserved 1 slots. As the lightpath L4 requires 1 slot, there are two links in Fig. 2(b): the one from node A to node D has 4 reserved slots; the other one from node D to node C has 1 reserved slots. The two links represent the first and the third lightpath, respectively. An example route from node A to node C derived by Dijkstra's shortest-path algorithm is also shown in Fig. 2(b), and a new lightpath L4 is provisioned. This route specifies that the new connection is first groomed onto the existing lightpath from node A to D by allocating more subcarriers, and then groomed onto another existing lightpath from node D to C. Considering the traffic grooming algorithm, L4 only uses the TP pairs of L1 and L3 without extra TPs, which increase TP utilization efficiently.

B. Dynamic Traffic-Grooming Strategy

When a connection request *r* arrives, a corresponding VAG is established according to the current network resources, and *r*'s bandwidth *b*. Then, we run *Dijkstra*'s shortest-path algorithm between the source and destination of *r* on the VAG to derive its route. The selected route determines whether and how we should establish new lightpaths (e.g., RSA) and/or which existing lightpaths the

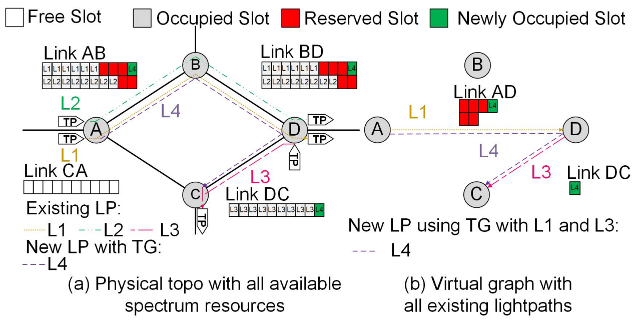

Fig.2. An example VAG

connection request *r* should be groomed onto. Meanwhile, a few numbers of slots are reserved according to the capacity of the TP and the maximum allowed number of reserved slots *M*. Moreover, if the path cannot be found on the VAG, we use first-fit policy and *Dijkstra*'s shortest-path algorithm for the RSA, and try to build a new lightpath on the optical-layer. If the new lightpath cannot be established, we assume that this demand is blocked due to network or TP contention.

C. Reserved Bandwidths Scheme

The motivation of the spectrum reservation for high-capacity TPs is that more connections can be groomed together and the capabilities of TPs can be utilized efficiently. We propose a spectrum reservation and assignment scheme that tries to allocate "just enough" spectrum to each pair of TPs according to their transmission capability.

To realize a spectrum reservation (SR) scheme, we reserve bandwidth adjacent to non-fully utilized lightpaths in the following two cases: 1) when a new lightpath is established, we try to reserve additional bandwidth for the newly-established lightpath; 2) when tearing down a connection, we keep the bandwidth of the expired connection as reserved for the lightpaths that the connection traverses, as long as the actual traffic amount on these lightpaths is not zero after tearing down the expired connection. We also define an integer variable $M \in [0, A]$ to constraint the maximum allowed number of slots a lightpath can be reserved. So the actual number of reserved slots for a lightpath is limited by both *M* and its spectrum contention with other lightpaths. We assume that the reserved spectrum can only be used by grooming new connections onto it, instead of using it by establishing new lightpaths.

IV. SIMULATION EVALUATIONS

In this simulation, lightpath requests arrive following a Poisson process with an average arrival rate of μ, and the holding time of each connection request follows the negative exponential distribution with an average value of λ time units; thus, the traffic load in the network is quantified as $L = \mu \cdot \lambda$ in Erlang. The 14-node and 21-link NSFNET is employed in this study, and the mini-grid spectrum partitioning with granularity g = 5 GHz is assumed, which is the same as the bandwidth of a subcarrier of an OFDM signal. Thus, each fiber has a total spectrum width of 1800 GHz (T = 360). The guard band is assumed to be 10 GHz (B = 2). The maximum transmission capacity of an OFDM TP is first set to be 100 Gbps (50 GHz, A = 10). And the possible number of reserved slots, *M*, is varied from [1, 3, 5, 7, 9], where the maximum value of 9 is only limited by the

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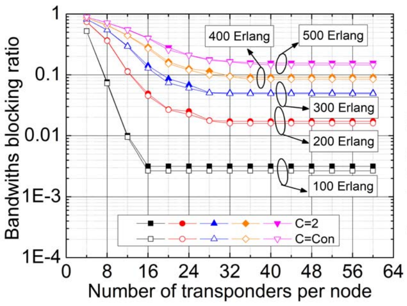

Fig. 3. Traffic Load vs. Number of Transponder

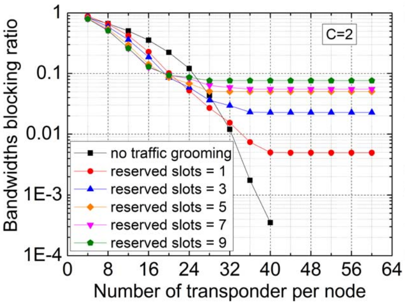

Fig. 4. Spectrum reservation schemes vs number of transponder

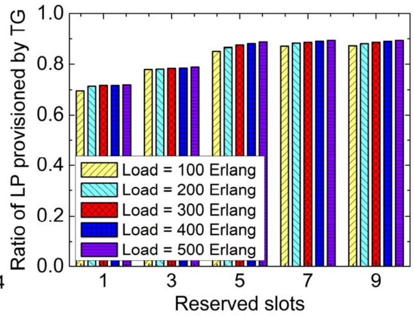

Fig. 5. Ratio of lightpaths provisioned by traffic grooming algorithm

TP capacity A and spectrum contention. There are three types of lightpath requests:10, 40, and 100-Gbps, with their proportion being10:4:1. Each data point in the graphs is averaged over 10^6 lightpath requests.

Fig. 3 shows the bandwidths blocking probabilities of the NSFNET under different traffic load with a fixed maximum reserved slots of 5. When the number of add/drop ports per node increase, the blocking performance of the network is significantly improved at the beginning, because the constraint of the number of TPs is relieved. And, when the number of TPs per node increase, the blocking performance is saturated, which means no further improvement is observed. This is because the number of TP is sufficient to avoid inter-node contention. The network-level inter-node contention becomes the main reason for blocking. Moreover, with the increase of the traffic, more TPs are required and the final blocking performance of the network becomes worse, which is owing to the constraint of the capacity of the network.

Fig. 4 shows the lightpath blocking probabilities of the NSFNET under the fixed traffic load of 300 Erlang with different maximum numbers of reserved slots. Similarly, with the increase of the number of TPs per node, the lightpath blocking performance is significantly improved at the beginning, and saturated at a certain point. At that point, TP resources no longer constrain the network performance. When the number of TPs per node is low, it is observed that the more slots allowed to be reserved, the better blocking performance can be achieved. This is because the TG strategy reserves certain spectrum for each active TP (existing lightpath) so that it has the spectrum to increase the number of subcarriers to accommodate future connections, thus more grooming opportunities are explored. In this way, TPs' bandwidth variability and transmission capability are efficiently utilized. In the contrary, when the number of TPs per node reaches higher, it is observed that the more slots allowed to be reserved, the worse blocking performance might be achieved. This is also reasonable. The increase of the maximum allowed numbers of reserved slots leads to more lightpaths that are established on electrical layer. And, the shortest path in VAG may use more physical hops than the shortest path in the optical layer. Due to the constraint of the network capacity, when these lightpaths use more spectrum resource, the bandwidths blocking ratio increased. So it is clear that there is a tradeoff between the TPs resources and the spectrum resources. Therefore, this TG should be wisely and adaptively used under different circumstances: if the network operator is more concerned about OPEX such as the number of used TPs, IP router ports, or energy consumption, more spectrum should be reserved; when spectrum resources are scarce and the network operator is more concerned about spectrum efficiency and blocking performance, less or none spectrum should be reserved.

For further study, the ratio of lightpaths established with TG strategy has been recorded in Fig. 5. It confirms that with the increase of the maximum allowed numbers of reserved slots, more connections are provisioned by TG strategy, because more spectrum recourse are reserved for TG. And, when the traffic load is high, more lightpaths are established on electrical layer. This is because TG strategy can distribute the spectrum recourse reasonable and make it easier to provision connections request on electrical layer. Moreover, according to [5], in most of the cases, C=2 TP banks are enough to match the performance provided by contentionless ROADMs. In our study, we confirmed this result, and there is almost no difference between the cases C=2 TP banks and cases C = contentionless TP banks, even in the TG cases.

V. Conclusion

In this paper, we evaluate a TG strategy with VAG in the EON to optimize the configuration of CD-ROADMs. This TG strategy considers both of the inter-node spectrum contention and the intra-node TP contention. Simulation result shows that the proposed TG strategy can reduce OPEX as well as increase TP efficiency by efficiently utilizing the bandwidth variability and transmission capability of optical TPs. There is also a tradeoff between the TPs resources and the spectrum resources, thus the TG should be adopted according to the network operators' objectives and network circumstances.

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