Auxiliary graph based energy-efficient dynamic connection grooming for elastic optical networks

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***Abstract*— We describe a reach-adaptive auxiliary graph based dynamic connection grooming scheme for elastic optical networks using multiple transmission options available with bandwidth variable transponders. We study different job scheduling methods and their impact on energy efficiency. The proposed scheme also incorporates efficient regenerator usage to improve the energy efficiency.**

***Index Terms*—Elastic optical network, energy efficiency, auxiliary graph, dynamic connection requests, regenerator**

I. Introduction

At recent times, core network designing using elastic-grid architecture shows promising results in terms of spectral efficiency and energy efficiency [1]. Elastic optical network (EON) uses a bandwidth variable transponder (BVT) to select a transmission option among multiple available options based on modulation format, baud rate, reach and spectrum allocation to transmit signal over a long distance with an acceptable quality of transmission (QoT). In EON, power consumption due to traffic flow through lightpaths (i.e., the all-optical paths) may vary depending on the transmission option used. To facilitate traffic transmission over a long distance signal regeneration at intermediate node(s) may be necessary to maintain acceptable QoT.

In [2], an energy efficient routing and spectrum assignment algorithm is proposed to minimize the energy consumption in EON with due consideration of regenerator placement. In [3], the authors describe auxiliary graph (AG) based dynamic traffic grooming for sliceable BVT enabled EON. In this study, we investigate a dynamic traffic grooming scheme for EON to minimize energy consumption by employing multi-optical-layer AG in order to consider all transmission options. We use several job scheduling methods to study their impact on energy consumption of network.

The rest of the paper is organised as follows. In Section II, we describe dynamic traffic grooming scheme taking into consideration practical network equipment and power consumption model, AG model and job scheduling methods. In Section III, we discuss simulation results and finally in Section IV, we present conclusion and future works.

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TABLE I: Multiple transmission options at BVTs [5]

Capacity (Gbps)	Reach (km)	Data Slots	Guardband Slots	Energy Consumption (W)	Capacity (Gbps)	Reach (km)	Data Slots	Guardband Slots	Energy Consumption (W)
40	4000	4	1	183.6	100	3500	4	1	270
	3000	3	1	183.6		3000	3	1	270
	2500	2	1	183.6		2500	2	1	270
	1900	1	1	183.6		1900	1	1	270
	600	1	1	154.8		600	1	1	198
200	2500	6	1	432	400	2500	14	1	630
	2200	5	1	432		2200	12	1	630
	1900	4	1	432		1900	10	1	630
	750	3	1	333		750	8	1	432
	600	2	1	333		600	6	1	432
	500	1	1	333		500	4	1	432

II. Dynamic Traffic Grooming

A core network is represented by a set of nodes (i.e., vertex) (V) and a set of bidirectional fibre links (i.e., edges) (E). We accommodate a set of dynamic connection requests (in the network) where a connection request ($r(s, d, b, t_h)$) is represented by the source node s, destination node d, bandwidth demand b and service/holding time t_h. We aim to optimize the overall energy consumption in the network by routing connection requests either through the existing/new lightpath(s) or the combination of existing and new lightpath(s) using different transmission options available with EONs.

A. Network Equipment and Power Consumption Model

Brief description of different equipment used for core networks and their power consumption model is as follows:

1) IP Core Router: We consider that an IP core router supports 400 Gbps router ports with each port consuming 1.4 W power per Gbps [4] (including the chassis overhead).

2) Bandwidth variable Transponder (BVT): We follow the architecture described in [5], [6] for BVTs. Energy consumption in BVT varies with the variation in the data rate and the transparent reach limit. Table I shows the power consumption for different transmission options available at BVTs. We consider the power consumption of a transmitter/receiver is equal to half of the power consumption of a BVT [7].

3) Optical Line Amplifier (OLA): We consider OLA supports spectrum width dependent amplification and needs to be placed after every 80 km of fibre span. An EDFA consumes 30 W power per direction [8].

4) Bandwidth Variable Optical Cross Connect (BV-OXC): As BV-OXC is not commercialised, we consider the OXC power consumption model used in the conventional WDM network. For 100% add-drop facility, power consumption equals to $(135 * d + 150)$ W [4], where d is the degree of node.

5) Elastic Optical Regeneraotor (EOR): EOR is used to reamplify, reshape and retime (3R) optical signal before signal gets distorted due to long distance transmission. EOR is visualized to be made of using multiple spectrum-selective subchannel regenerators (SSRs) [9]. EOR can be used to implement distance-adaptive modulation format conversion to save energy and (or) spectrum slot (in outgoing optical channels). As EOR has the same components as in BVT, we consider the same power consumption for EOR and BVT.

B. Auxiliary Graph (AG) Model

With arrival of each connection request, an AG [10] is constructed. Traffic processing occurs in two layers: electrical layer and optical layer. IP core routers perform electrical layer processing, while BVTs perform optical layer processing using multiple transmission options.

Fig 1 shows an example of a 3-node network topology with nodes A, B and C. Considering 3 types of transmission options available with BVTs, an AG has 3 optical layer nodes for each physical node. As for an example, node A is represented by electrical layer node A_E and optical layer nodes A_1, A_2 and A_3. AG has three types of edges between nodes, namely, *lightpath edge, transponder edge,* and *transmission edge*. A connection request generates and terminates at the electrical layer of two physical nodes. For a given connection request, two electrical layer nodes are considered to have a lightpath edge if there exists a lightpath between the nodes with free capacity to accommodate the connection request. Lightpath edge weight depends on the energy consumption for traffic grooming only. Transponder edge (i.e., Tx/Rx edge) exists between an electrical layer node and any of the optical layer nodes of the same physical node if a free BVT is available. A transponder edge is bidirectional in nature representing an unidirectional transmitter (Tx) edge and an unidirectional receiver (Rx) edge. Transponder edge weight is represented by the power consumption for the relevant transmission option using BVT. Transmission edge exists between two different physical nodes within the same optical layer. Transmission edge weight depends on the number of required slots (for the given BVT transmission option), availability of required slots in fibre, and the energy consumption of OLA. It is only possible to connect between different optical layers if regenerator is available at the node and all other constraints (e.g. availability of spectrum slots) are satisfied.

For an example, let the distance between nodes A and B is 1500km and nodes B and C is 900km. Regenerator is available only at node B. Maximum transparent reach for optical layers 1, 2 and 3 are considered as 1000km, 1500km and 2000km, respectively. So, for optical layer 1, there is no edge from node A to node B due to inability to reach node B from A using 1st transmission options. If a lightpath edge exists between node A to node B, traffic flow from A to C may occur using path $A_E - B_E - B_1 - C_1 - C_E$. If the lightpath edge is not available, another possible path will be $A_E - A_2 - B_2 - C_1 - C_E$. At node B, signal regeneration occurs and transmission option 1 is used for upward transmission to node C.

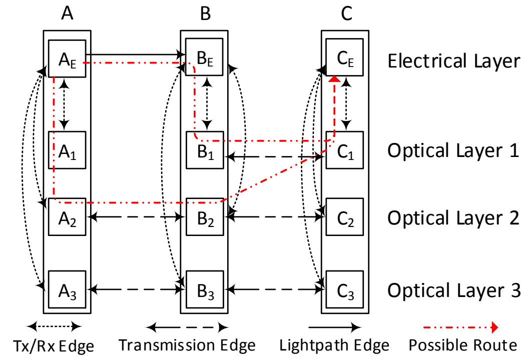


Fig. 1: Auxiliary Graph.

For a given connection request, an AG is constructed and the shortest path is computed from the source node to the destination node based on the AG. The connection request is accommodated along the path.

C. Job Scheduling

For a given time interval, all incoming connection requests are collected and scheduled. We explore different job scheduling (JS) strategies depending on bandwidth demand and holding time of connection requests as described in Table II. As for an example, for JS2, connection requests are provisioned based on the least deviation from the average bandwidth demand and if the bandwidth of two connection requests (with the same deviation from the average value) becomes equal, connection requests are provisioned in increasing order of holding time.

TABLE II: Job Scheduling

Sl. No.	1st Priority	2nd Priority
JS1	Random	
JS2	Average Bandwidth	Small Holding Time
JS3	Small Bandwidth	Small Holding Time
JS4	High Bandwidth	Small Holding Time
JS5	High Bandwidth	Large Holding Time
JS6	Small Bandwidth	Large Holding Time

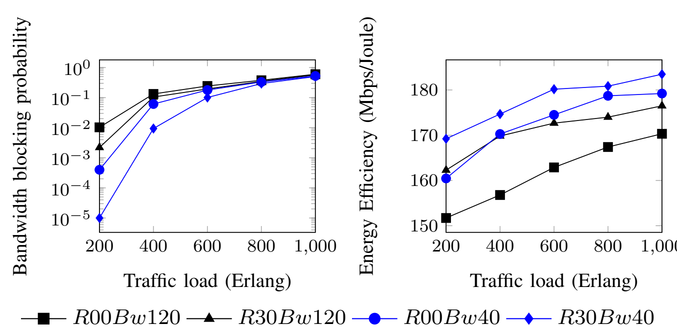
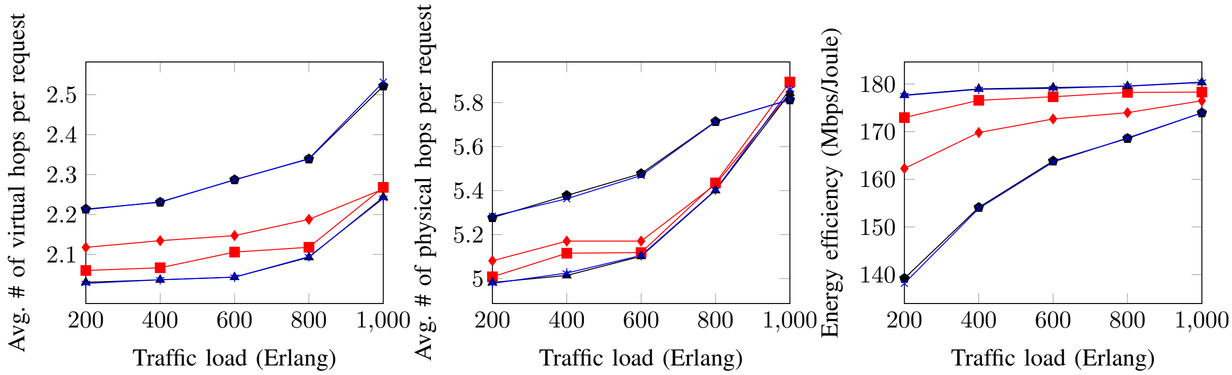


Fig. 2: Results for different average bandwidth demands with/without regenerators.



(a) Average # of virtual hops per request (b) Average # of physical hops per request (c) Energy efficiency

JS1 JS2 JS3 JS4 JS5 JS6

Fig. 3: Simulation results for different job scheduling methods.

Time complexity to accommodate an incoming connection request is higher than the time complexity to free resources for an outgoing connection request. The worst case time complexity to accommodate an incoming connection request is $O(MNN_a^2)$, where N is the number of nodes and N_a is the number of auxiliary nodes; M is the summation of N_a and the product of the number of auxiliary nodes per node with number of nodes having regenerators.

III. Numerical Examples

We study performance of the proposed dynamic traffic grooming scheme for USNET 24-node network with realistic distance between nodes. Each fibre is considered to be bidirectional and operated at C band with contiguous spectral window having slot width of 12.5 GHz. The Number of router ports and transponders at each node is fixed at 32. Connection arrival process follows Poisson distribution and holding time follows exponential distribution. Bandwidth demand is uniformly distributed within [5, $2X$-5] Gbps, where X is the average bandwidth demand. Source-destination pairs for connection requests are chosen through uniform random distribution. Simulation data points are averaged over 10 simulations and we use 10^5 connection requests for each simulation. We consider two scenarios: with or without regenerators. When regenerators are considered, we do not address the regenerator placement problem. We assume that regenerators are placed at the top 30% of the nodes with the highest degree.

In Fig. 2 we compare bandwidth blocking probability and energy efficiency for the scenarios with/without regenerators. We consider two types of traffics: low (with $X = 40$Gbps) and high (with $X = 120$Gbps). In presence of regenerators, bandwidth blocking probability and energy efficiency improve compared to the case without regenerators. Figs. 3a, 3b and 3c show performances of different job scheduling methods only for the scenario with regenerators and 120Gbps average bandwidth demand. Fig 3a shows that with increase in traffic load, the average number of virtual hops per connection increases. Fig 3b shows that with increase in traffic load, the average number of physical hops per connection increases. Fig 3c shows that scheduling with higher bandwidth first (i.e., JS4 and JS5) gives the best energy efficiency, whereas smaller bandwidth first (i.e., JS3 and JS6) gives the poorest performance. We also observe that JS2 performs better than JS1.

IV. Conclusion

In this study, we propose a dynamic connection grooming scheme for different job scheduling methods. Using AG we consider multiple transmission options available with BVTs and employ reach-dependent regenerations. Simulation result shows that deploying regenerators considerably improves bandwidth blocking probability and energy efficiency at low or high average bandwidths. Job scheduling methods with higher bandwidth first offer the best performance, followed by the methods with average bandwidth first, under all traffic loads. We wish to incorporate sliceable BVT and optical grooming in our future work.

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