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Energy-Efficient Traffic Scheduling in IP over WDM Networks

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Abstract— In this paper, we investigate the energy efficiency that can be achieved by using traffic scheduling in IP over WDM networks. A mixed integer linear programming model is developed to optimize routing and scheduling in dynamically arriving demands, where part of the demands can be allocated within a sliding window. The results show that scheduling improves the energy efficiency of non-bypass IP/WDM networks, with traffic grooming by up to 25% and blocking is reduced by 30%.

Index Terms—Traffic scheduling, Advance Reservation, Energy-Efficiency

I. INTRODUCTION

In this digital era, the demand on communication networks has increased tremendously due to the introduction of new bandwidth-intensive applications such as video and file sharing services. This has pushed service providers to use more powerful and power-hungry equipment, which consequently leads to huge power consumption. Reports estimate that the ICT contribution to CO_2 emission is very significant and comparable to the aviation industry, contributing 2.3% of the overall CO_2 emission worldwide [1]. This ecological and economic impact of the increasing power consumption is driving both the industry and academia to search for energy efficient approaches and systems.

The introduction of Wavelength Division Multiplexing (WDM) technology has provided huge transport capacities, making it the widely deployed technology in backbone networks. The transported optical signals carry information aggregated by IP routers after being converted from the electrical to optical domain. Although the current shape of the network has undergone several improvements by removing many layers and using only the IP and the WDM layers, the network has a diverse set of devices collectively performing the desired information transfer, such as aggregation, routing, optical-electrical conversion, optical amplification and switching. These pieces of equipment differ in their power consumption behaviour and improve energy efficiency, considering the network specifics that need to be studied. Energy efficiency has been studied in WDM networks by considering different approaches and scenarios. The readers are referred to [2] for a good survey about these efforts. In our previous works, we have studied energy-efficiency in IP over WDM core networks with renewable energy sources [3] with distributed clouds [4], virtualizing network resources [5], improving energy efficiency in IPTV [6], physical topology design [7], with data centres [8] and peer to peer content distribution [9].

Although previous work has produced significant improvements in energy efficiency, it considered models where traffic demands are served in a given time point. This is not the general case, as an increasing amount of applications have the flexibility to be served within a specified time window. Examples of such applications include data centres synchronisation, offsite backups and e-science applications. This adds another degree of freedom and changes the problem from only routing to routing and scheduling.

The authors of [10] reported savings of 7%-40% by changing the demands overlapping factors to groom sub-wavelength demands as much as possible and maximize the switched-off unused lightpath, while in [11] they achieved a power saving of 10% in the scheduling scenario as compared with the non-scheduling scenario in a 6-node network with 4 sub-wavelength demands. Their saving came from grooming these demands by sliding the start time of the request. In [12], the authors investigated the power savings by traffic grooming in both static and dynamic traffic demands. The authors evaluated the power saving with three types of traffic overlapping scenarios. They achieved a power saving of 10% by increasing the demands overlapping. The work in [13], studied the impact of the sliding window size using a heuristic.

The previous studies did not consider the realistic scenario, in which the network receives the demands in a semi-dynamic form and starts scheduling time point by time point in a first come first served manner. Also, they evaluated the models on sample networks with few demands. In this work, we evaluate the scheduling by applying real traffic values on NSFNET topology.

In this paper, we contribute to the energy-efficient traffic scheduling approach in IP over WDM networks by considering grooming and traffic bifurcation in a dynamic form, where demands are decided at each time point rather than the static scheduling that has full knowledge of current and future demands. We consider the NSFNET as a realistic core network and consider realistic demand sizes and counts. We also examine the improvement in blocking in addition to energy efficiency. We have developed a Mixed Integer Linear Programming (MILP) model to solve the problem of immediate and advance reservation problems for scheduled demands with the objective of minimizing the total power consumption.

The remainder of this paper is organized as follows: in Section II the traffic scheduling model will be explained, Section III will present and discuss the results before, finally, the paper is concluded in Section IV.

II. TRAFFIC SCHEDULING MODEL

In this section, we explain the developed MILP model that minimizes the power consumption of scheduled traffic in IP over WDM networks with a non-bypass lightpath approach. In non-bypass, the traffic should be terminated at each intermediate IP router before continuing its journey towards the destination node.

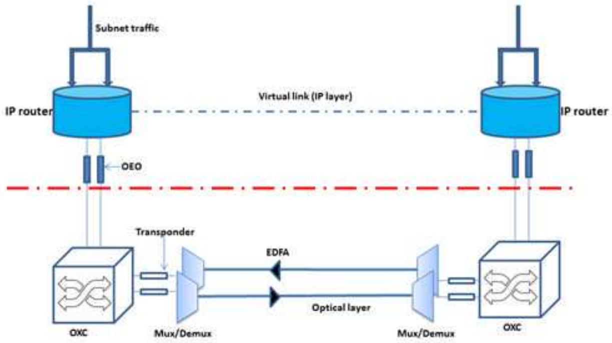

Fig. 1 IP over WDM Network Architecture

Fig. 1 shows the IP over WDM nodes architecture considering two nodes. In the IP layer, IP ports perform traffic aggregation from edge routers and transponders provide the interface to Optical Cross Connects (OXC) by converting between the electrical and the optical domain. Multiplexers/demultiplexers are used to multiplex/demultiplex multiple wavelengths in an optical fibre. Erbium doped fibre amplifiers (EDFA) are used to amplify optical signals to support communication over long distances, and many EDFAs may be required in each fibre depending on its length.

Generally there are two types of traffic allocation schemes: static and dynamic. In the static model, demands are known in advance, while in the dynamic type the demands arrive one by one and require resources upon arrival. Also, the traffic models can be classified as immediate or advance reservation [14]. The reservation is for the required resources that should be allocated at the demand service time. The provisioning could be either immediate or in advance. In the immediate reservation, whenever the demand arrives at the network, the process starts by routing and allocating resources along the path, while in the advance type there is a holding time for the request until they start to be served for the demand duration.

We evaluate the model using the NSFNET topology shown in Fig. 2. The NSFNET covers the US and consists of 14 nodes and 21 bidirectional links. Fig. 2 shows node locations and links distances, which dictates the amount of EDFAs used on each link. Fig 3 shows the average traffic demand variation during the day [15]. The average traffic demand between each node pair ranges from 20 Gb/s - 120 Gb/s, and the peak hour is 22:00. The traffic demand between the node pairs ranges from 10 Gb/s to 80 Gb/s, and the demand duration is exponentially distributed with a mean of 4 hours. The window size ranges from 2-6 hours and is uniformly distributed.

We compare the two approaches: the first assumes that all traffic requests require a fixed starting time, either immediately upon arrival or later in the future as an advance reserved, with IR demands of 10 % and 90% of all requests (we call it Fixed Advance Reservation (FAR)). In the second approach we included the traffic that is reserved in advanced but can start during a sliding window. The second assumption involves 10 % immediately reserved demands, 40 % to start at a fixed time in the future and 50 % is of the sliding advanced request type. We call this approach the Sliding window Reservation (SAR). The sliding window size of the SAR requests is uniformly distributed between 2-6 hours.

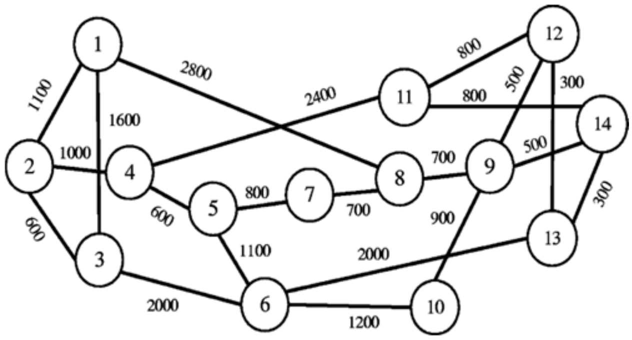

Fig. 2 The NSFNET network

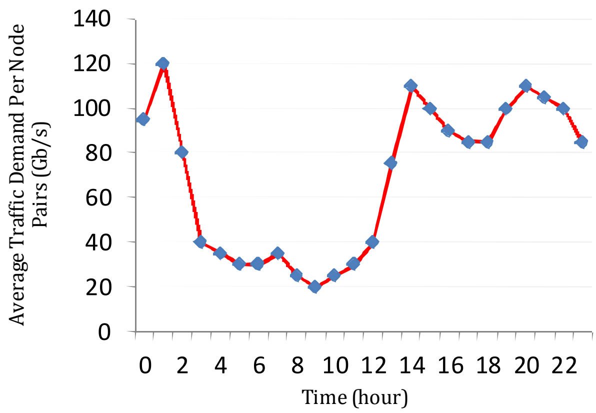

Fig. 3 Traffic profile

The model optimizes the allocation of network resources to meet the requirements of the scheduled requests at each scheduling time slot, so the total network power consumption is minimized while maintaining QoS. The objective function of the model is given as:

Objective: Minimize the total power of the network at a given time:

$$\sum_{m\in N}\sum_{n\in N_m}(p_r w_{mnt} + p_t w_{mnt} + p_e f_{mn} A_{mn}) + \sum_{m\in N} p_o x_m \quad (1)$$

where w_{mnt} is the total number of wavelengths used between the node pair (m,n) at time t and f_{mn} and A_{mn} are the number of optical fibres and number of EDFAs in link (m,n) respectively. The values p_r , p_t , p_e and p_o are the power consumption values for router ports, transponders , EDFAs and optical cross connects respectively. Table 1 presents the power consumption values of different network devices based on the best commercially deployed 2010 technologies [16].

According to nodes distances (L_{mn}) , number of EDFAs in link(m,n) can be calculated using [17]

$$A_{mn} = \left\lceil \frac{L_{mn}}{S} - 1 \right\rceil + 2 \quad (2)$$

Table 1: Network Parameters.

Parameter	Value
Distance between neighboring EDFAs (S)	80 km
Number of wavelengths in a fiber	32
Capacity of each wavelength	40 Gbps
Power consumption of a router port (p_r)	440 W
Power consumption of a transponder (p_t)	148 W
Power consumption of an Optical Switch (p_o)	85 W
EDFA's power consumption (p_e)	52 W

The model maintains the virtual and the optical layer capacity conservation constraint and capacity constraint. It also maintains flow allocation under available allocation window constraint while ensuring continuous allocation. We executed the MILP model on a High Performance Computer (HPC) with 256 GB RAM and 16 cores for a realistic evaluation of a realistic core network with the size of the NSFNET and a realistic set of traffic demands.

III. Results and Discussion

We investigate the power savings achieved when we implement the sliding window advanced reservation approach (SAR) with traffic grooming compared to the fixed advanced reservation (FAR) approach. We consider two scenarios: first, we study the (FAR) case with no grooming, and second, we enable grooming for both approaches. Fig.4 shows the power consumption of the SAR with groomed traffic compared to the FAR approach with no grooming. We find from the figure that the sliding window with the grooming approach can achieve an average power saving of 25%.

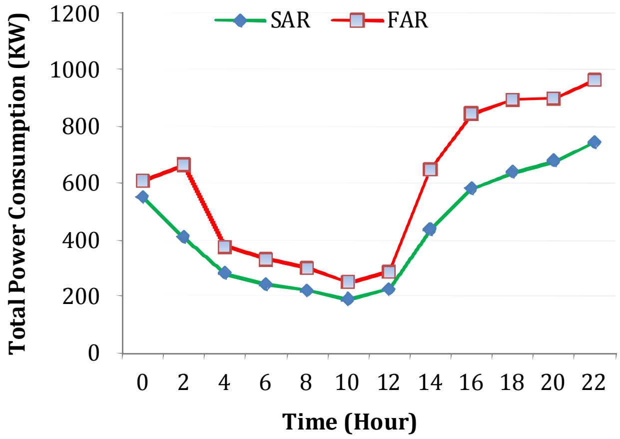

Figure 4: Network total power consumption for FAR without grooming vs SAR with grooming

When we compare the two approaches when both employ the grooming functionality, average savings of 2.6% are achieved as shown in Fig.5. The figure also shows that the SAR approach is most of the time more power efficient than the FAR approach, except for some time point where the FAR approach is slightly better. This is due to the dynamic nature of the system, where demands are scheduled upon arrival. However, overall it is superior to the FAR approach. This 2.6% saving is accompanied by a significant reduction in blocking. Fig.6 shows the blocking probability of the two scenarios. The SAR approach reduces the average blocking by 30% compared to the FAR approach. Fig.6 shows that blocking for the (FAR) scheme starts during the peak hours and increases afterwards as a result of accumulated demands and lack of rerouting due to the dynamic behaviour. Already routed demands that can't be altered increase the difficulty of finding alternative routes and schedules. This indicates a possibility of improving the savings if there exists the option of rerouting already routed demands on top of scheduling advanced demands.

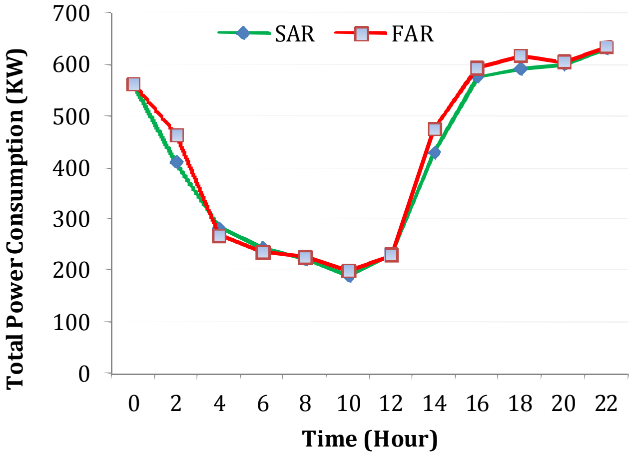

Figure 5: Power consumption for the fixed and sliding window approaches

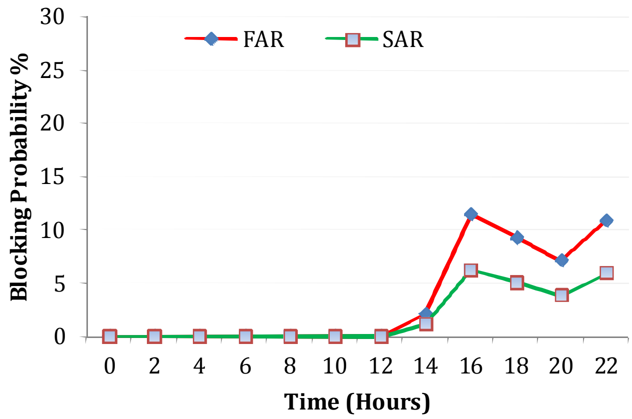

Figure 6: Blocking probability % for the fixed and sliding window approaches

To evaluate the effect of static allocation as opposed to the dynamic allocation shown in the previous cases, we have re-evaluated the results of Fig.5 for the static approach, where we have a global view of the demands for the next day and demands can be scheduled and routed. Fig.7 shows that this can achieve up to 5% power saving and eliminates blocking.

The results of the model indicate that bifurcation is used to maximize traffic grooming. Improving bifurcation may lead to more grooming, but it is limited by the increase in the hop count between the possible set of paths. The fact that there is a limited set of paths for each demand suggests that a heuristic which checks a small set of paths and a small set of starting times for the sliding window requests may be sufficient to achieve close to optimal results compared to the approach that exhausts all paths and starting times, therefore improving energy efficiency and reducing blocking in an arbitrary small running time. Other dimensions worth considering as a future expansion include the impact of the percentage of sliding window demands to the total traffic demands, as well as the distribution, the size of the sliding window and the duration of each demand.

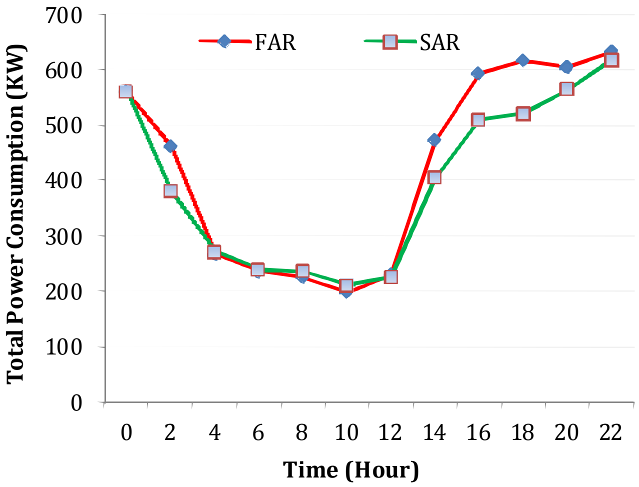

Figure 7: Power consumption for the fixed and sliding window approaches considering static allocation

IV. Conclusions

In this work we investigated an energy efficient scheme for allocating network resources to scheduled traffic requests where large bandwidth connections are required for a certain period of time and have the flexibility to be served within a given window. We reported the results of a MILP model we developed considering realistic core network traffic in the NSFNET. Our objective is to optimize the network resource allocation in non-bypass IP over WDM networks considering different classes of scheduled traffic requests. We have considered different scenarios to evaluate the scheduling of the two types of advance reservation demands, the fixed advanced reservation (FAR) and the sliding window reservation (SAR). The MILP results suggest that exploiting the nature of some traffic demands that have flexible starting times and employing grooming can improve energy efficiency by 25% and reduce blocking by 30% when demands are served dynamically. The results also suggest that more savings can be achieved if traffic demands can be rerouted.

Acknowledgments

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