Exploiting Traffic Dynamics in Power-Aware Logical Topology Design

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Abstract: We propose the Multi-Period Power-Aware Logical Topology Design. We compared two different heuristics and show that exploiting the day-night fluctuations of the traffic can lead to significant power savings at a low reconfiguration cost.

OCIS codes: (060.4510) Optical communications, (060.4250) Networks

1. Introduction

Recent studies show that the Information and Communication Technologies (ICT) sector is responsible for a significant percentage of the worldwide power consumption. According to estimations in [1], the worldwide operations of network equipment accounts for 25 GW (yearly average) of the total ICT consumption. While the joule/bit in telecommunication networks is decreasing with time, the joule/user keeps steadily increasing.

Optical technologies offer huge bandwidth at low power cost. As the traffic volume increases and access solutions shift from xDSL to PON, the major fraction of power consumption is moving from access to backbone network [2]. Hence, the design of energy-efficient backbone networks becomes essential to reduce power requirements of future Internet. Today's core segments of the networks are usually implemented using Wavelength Routing (WR) optical networks. Traffic in WR networks is carried by optical circuits, called lightpaths, which are optically switched at intermediate nodes without the need of electronic processing. The design of WR networks requires solving both the Logical Topology Design (LTD) (in which the set of lightpaths is determined) and the Routing Wavelength Assignment (RWA) (in which the lightpaths are routed over the physical topology).

In this work we propose the Multi-Period Power-Aware LTD (MP-PA-LTD), i.e., an LTD which exploits the time dimension to provide power-aware solutions. In the following, we describe the MP-PA-LTD, the considered costs of reconfiguration and the network model. Next, we propose two different heuristics able to efficiently solve the MP-PA-LTD. In Section 3, we present a case study based on a real network and traffic measurements and Section 4 conclude the work.

2. Multi-Period Power-Aware Logical Topology Design

In the MP-PA-LTD, we exploit the dynamic nature of traffic, which is not constant in time, but usually follows a day-night pattern with high traffic demands during the day and low traffic demands during the night. Today, network resources are allocated to constantly satisfy the maximum demands. These resources consume energy even if not used or underutilized. Indeed, power consumption in currently deployed network devices is basically independent of load in today's routers. Therefore, we divide the day into smaller time periods. Each period is characterized by a Traffic Matrix (TM) used to design the Logical Topology (LT) for the current period. Configuring the network for each of these periods allows to utilize resources to a higher extent, and consequently power can be saved by switching off some devices. An issue of this approach is that the network has to be reconfigured between two consecutive time periods. Reconfiguring means adding or deleting lightpaths from the LT, but also changing the routing of the traffic over the LT. In this work we consider the latter. Therefore, we define the reconfiguration cost for each lightpath as the amount of new traffic that has to be routed on the ligthpath at the beginning of the new time period.

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n. 257740 (Network of Excellence "TREND").

2.1. Network model

We consider a backbone IP-over-WDM network. Resources (Optical Cross-Connects (OXCs) and fibers) at the physical layer are used to realize the LT at the IP layer. We model the LT as a directed network composed of nodes and logical links. A logical link consists of all the lightpaths established between a corresponding pair of IP routers, independently of their realization in the physical topology. Each lightpath is terminated by a transmitter and a receiver located in the line card, which, together with the corresponding transponder, is subject to switching on and off for power saving. An OXC, which is responsible for switching lightpaths at the optical layer, and an IP router, which allows grooming of several traffic demands into a single lightpath, are installed at each node of the network.

We adopt a node model consistent with the NOBEL model [3]. Each IP router is equipped with line cards (short-reach interfaces) connected to transponders, which perform E/O and O/E conversion. Moreover, the IP router is modeled according to the structure of the Cisco CRS-1 router, using publicly available power consumption values [4]. We assume that a lightpath has capacity $C = 40$ Gbps, thus, we select a "Cisco CRS Single-Port STM-256c POS Interface Module" with the "Modular Services Card" as a line card and the "Tellabs 7100 Optical Transport System Forty Gigabit Transponder Module" as a transponder. The total power consumption of these three devices equals 667 W.

IP routers are composed of one or multiple line card chassis interconnected by fabric card chassis dependent on their capacity (see [4]). Chassis can be switched off if all the corresponding line cards are switched off.

Since we focus on the LTD, we assume that the physical topology has enough capacity to map the LTs over it.

2.2. Multi-period heuristics

In the following, we briefly introduce the algorithms that we propose to solve the MP-PA-LTD.

Least Flow Algorithm We consider the Least Flow Algorithm (LFA) of [5]. The proposed algorithm starts from a static base network, which is an LT designed for the maximized traffic matrix obtained selecting the maximum demand for any source-destination pair among all the TMs. Initially, logical links are sorted by increasing volume of carried traffic of current TM. Then, the algorithm iterates through the sorted list of logical links trying to turn them off. It verifies for each given link, if network connectivity and maximum link utilization constraints can be met upon switching the link off and rerouting traffic. The link is powered off only if this is the case. This procedure is repeated for each TM.

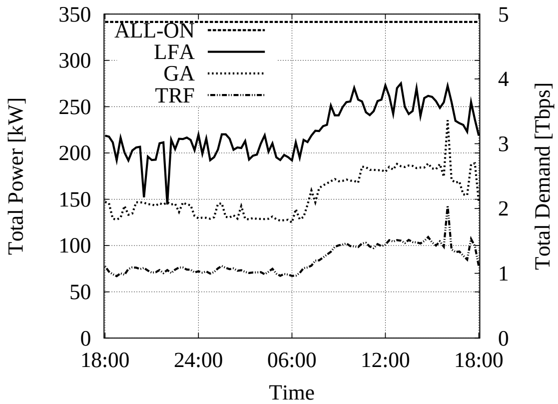
Genetic Algorithm We then consider the Genetic Algorithm (GA) firstly proposed in [6]. The GA is a meta-heuristic which is based on the principles of natural evolution. Fundamental concepts of the GA are the definition of an individual, which identifies a feasible solution of the problem, and of the fitness function, which indicates how suitable a given individual is. As in [6], the individual codifies a possible LT, i.e., an array containing the number of lightpaths to be established between any pair of nodes. Differently from our previous work, the fitness function is defined as the weighted sum of the power consumption and of the reconfiguration costs. Thus, the GA performs a multi-objective optimization trying to find the best trade off between the power consumed and the costs required to configure the network.

3. Results

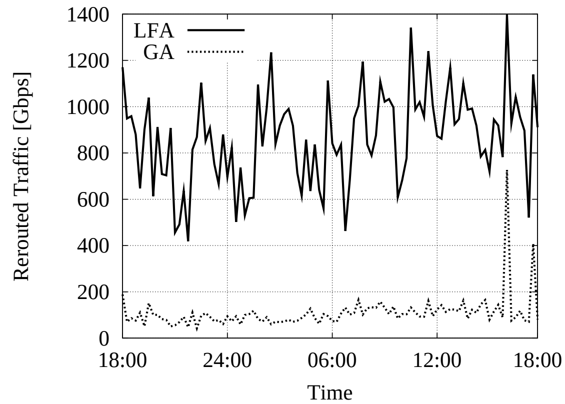
The following input data is required for the MP-PA-LTD: one TM for each time period, and for the LFA, the static base network designed for the maximum TM. We use 96 TMs originating from measurements in the 12-node Abilene network [7] from 18:00 on 2004-05-31 to 17:59 on 2004-06-01 MDT (we assume UTC for the original traffic matrices in [7]). In particular, we scale them up to 3 Tbps of total demand to match actual traffic demands. Moreover, we consider a time period of 15 minutes between two consecutive TMs, since we believe it is long enough to calculate appropriate network configuration and perform the reconfiguration, but short enough to capture the essential mid-term traffic dynamics. Original TMs are measured every 5 minutes, thus, we select the maximum values over the current time period for each source-destination pair.

The static base network, which is used by the LFA algorithm, has been retrieved by the GA in order to satisfy the maximum traffic demands for any TMs. The network should be configured using the static base network, in the case that the multi-period approach is not adopted.

We run the proposed heuristics for each TM. Fig. 1(a) reports the comparison of the considered heuristics in terms of power consumption during a day. The figure reports also the power consumed by the static base network, labeled ALL-ON. TRF denotes the total demand of the matrices. Both heuristics follow the same trend of TRF, suggesting that a large number of resources can be switched off during low-demand hours. In particular, LFA saves more than 37% of power with respect to the ALL-ON configuration during off-peak hours. Then, the best savings are obtained



(a) Power consumption follows the traffic pattern for LFA and GA.



(b) GA limits amount of rerouted traffic.

by the GA heuristic, with more than 55% of power saving during the night. Part of the difference between the two approaches is due to the fact that GA considers switching single lightpaths off, while LFA focuses on entire virtual links. Thus, GA is able to better exploit the lightpath resources to aggregate traffic and therefore saving more power by turning off higher number of resources. In addition, GA intrinsically minimizes power while LFA simply tries to switch off network devices while ensuring connectivity, independently from their power consumption.

We then consider the reconfiguration costs for the LFA and GA heuristics. Fig. 1(b) reports the amount of traffic that is rerouted at each algorithm run, i.e. at each TM. Since the GA minimizes both power and reconfiguration costs, it outperforms LFA, with an amount of rerouted traffic bounded below 200 Gbps during off peak hours. In particular, for each subsequent TM, GA starts from the previous network configuration, while the LFA algorithm starts always from the ALL-ON configuration, resulting in a large quantity of traffic that is shifted from the resources that are switched off.

4. Conclusion

We have presented the Multi-Period Power-Aware LTD (MP-PA-LTD) problem for IP-over-WDM networks, in which the objective is to reduce the total power consumption and the amount of rerouted traffic as network devices are switched off. We have evaluated different heuristics to solve the original problem. Results show that large power savings are possible, while limiting the traffic that is reconfigured in the network. Future work includes investigating the proposed solutions on realistic architectures, studying also the impact of routing algorithms on total power consumption.

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