Performance Evaluation of an Impairment-Aware Lightpath Computation Engine

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Abstract *We present a network operation tool called Impairment Aware Lightpath Computation Engine (IALCE) that incorporates an impairment-aware routing and wavelength assignment (RWA) algorithm. We perform experiments illustrating the flexibility of the engine and the performance of the algorithm.*

Introduction

In transparent optical networks data is transported over lightpaths. Physical layer impairments accumulate as the optical signal propagates over the lightpath degrading its quality to the extent that reliable signal detection at the receiver may be infeasible. Considering physical layer impairments when selecting the lightpath gives rise to the Impairment Aware Routing and Wavelength Assignment (IA-RWA) problem[1].

The network planning phase typically occurs before a network is deployed, and aims at accommodating a given set of connection demands (traffic matrix), assuming that any equipment required by the plan can be employed. The planning phase results in some initial network configuration and is followed by the network operation phase where any additional demands that may arise are processed upon their arrival and one at a time. It is desirable for the additional traffic to be accommodated using whatever equipment is already deployed in the network. Therefore, IA-RWA algorithms in the operation process must take into consideration the existing connections and the constraints posed by the current state of deployed equipment, which, for instance, may force a demand to be routed over a sub-optimal route.

In this work we present a network operation tool called Impairment Aware Lightpath Computation Engine (IALCE), which is developed in the course of DICONET[2] project. In what follows we give a brief overview of IALCE and evaluate its performance as a network operation tool, in terms of success rate for various dynamic traffic scenario, running time, and quality of IA-RWA solutions provided.

Anatomy of IALCE

The main functionality of IALCE is to receive a connection request for a given source-destination pair, and to return a lightpath (i.e., route and wavelength/channel) for serving the request, considering the network topology and physical layer performance. The building blocks of our IALCE are depicted in Fig. 1. The network description (physical layer and topology) is included in two main repositories. The Physical Parameters Database (PPD) records the physical characteristics of the links, nodes and components on the links, while the Traffic Engineering Database (TED) records the network topology and the current utilization information. The Network Description Generator module automates the generation of these two repositories. The IALCE XML parser is responsible for parsing the network repositories and transforming the network description into an internal representation inside the IALCE memory. The Q-Tool module is the Quality of Transmission

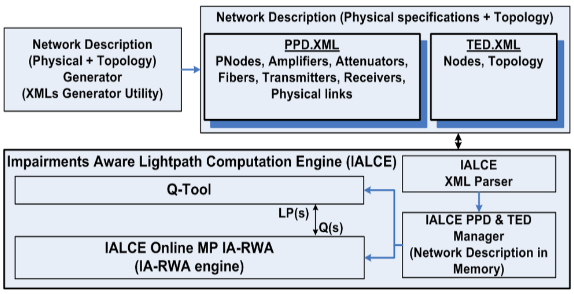

Fig. 1: Building blocks of IALCE.

(QoT) estimator that considers most of the dominant physical impairments of a WDM system and incorporates their impact into a single figure of merit, namely the Q-factor. In particular, Q-Tool estimates the Q-factor of a set of lightpaths, given all the necessary topological and physical layer characteristics, and the current utilization status of the network. Q-Tool estimates the distortion-induced eye closure that defines the impact of the combined effect of Self Phase Modulation (SPM), Chromatic Dispersion (CD), Filter Concatenation (FC), and Polarization Mode Dispersion (PMD). It also considers the impairments that introduce degradations at the amplitude levels, i.e., Amplified Spontaneous Emission noise (ASE), Cross

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Phase Modulation (XPM), and Four Wave Mixing (FWM). The IA-RWA algorithm, which is incorporated in IALCE is named Multi-Parametric (MP) IA-RWA Engine[4]. It receives a demand request, in the form of a [source, destination, protection level] tuple and computes the lightpath for serving this request. In the Multi-Parametric approach, a vector of cost parameters is assigned to each link, from which the cost vectors of candidate lightpaths are calculated. The cost vector includes impairment generating source parameters, such as the path length, the number of hops, the number of crosstalk sources and other inter-lightpath interfering parameters, so as to indirectly account for the physical layer effects. For a requested connection the algorithm calculates a set of candidate lightpaths, whose QoT is approximated using a function that combines the impairment generating parameters. A lightpath is rejected if the value produced by the function is larger than a predefined threshold, which characterizes the lightpaths with acceptable QoT. For selecting the lightpath various optimization functions can be used. In the end, the decided lightpath is also evaluated using the actual Q-Tool. In addition, the Q-factor of the already established lightpaths are also evaluated so as to check whether the establishment of the new lightpath will turn infeasible some of the existing ones, in which case the new lightpath is blocked.

Simulation setup

We selected Deutsche Telekom's national network (DTNet) for our simulation studies. This network has 14 nodes and 23 bidirectional links, with an average node degree of 3.29. The physical characteristics of DTNet are summarized in Fig. 2. In our tests we assume an "arrivals only"

Parameter	Value
Input power	-4 (SSMF), 3 (DCF) dBm
Pre-dispersion compensation	-85 ps/nm
Span length	70 km
Dispersion parameter	17 (SSMF), 80 (DCF) ps/nm/km
Attenuation	0.23 (SSMF), 0.4 (DCF) dB/km
PMD	0.1 ps/(km)$^{1/2}$
Channel spacing	50 GHz
Amplifier noise figure	6 dB
Mean under compensated dispersion	80 ps/nm per span
Q-factor threshold	15.5 dB (BER=10^{-9} without FEC)
Line rate:	10 Gbps

Fig. 2: Physical characteristics of DTNet.

scenario, were connection requests, each having infinite duration, arrive one by one and have to be served efficiently and fast upon their arrival. Under this scenario the exact arrival process of the requests does not affect network performance; instead, their characteristics (source, destination nodes) are important. In our tests the number of requested connections varies. The characteristics of these demands were based on the traffic of the DTNet for 2009, by escalating it by a factor L (0.2, 0.4, 0.6, 0.8, 1, 1.2). In what follows we refer to this factor L as the network load. Fig. 3 shows the GUI of IALCE and in particular the visualized results of the MP IA-RWA algorithm. Though in our tests IALCE operates in a standalone mode, it can also be installed in an actual optical network, cooperating with a control plane mechanism for network information collection, dissemination and lightpath establishment[3].

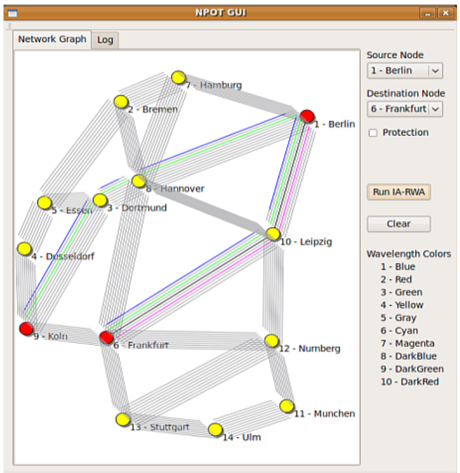

Fig. 3: The established lightpaths on IALCE's GUI.

Results

Fig. 4 shows the ratio of successfully established connections as a function of the number of available channels W per fiber, for various network loads. The load in the network affects the success ratio, since when more connections request service the ratio of successfully served connections decreases, even if there are many available channels. Fig. 5 illustrates the average execu-

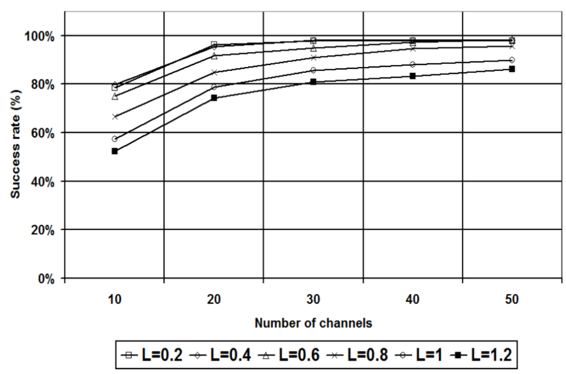

Fig. 4: The success rate versus the number of available channels W per fiber.

tion time (in seconds) per connection request of IALCE, for different number of available channels and traffic demands. A large number of available channels increases IALCE's execution time, since in this case more candidate lightpaths are calculated by the MP algorithm. In addition, when the number of established lightpaths is large, then the Q-factor value of many of these (affected) lightpaths has to be evaluated before a new/candidate lightpath is established; increasing in this way the total execution time. In any case, as illustrated in Figure 4, IALCE's execution time is acceptable and appropriate for online mode. In our

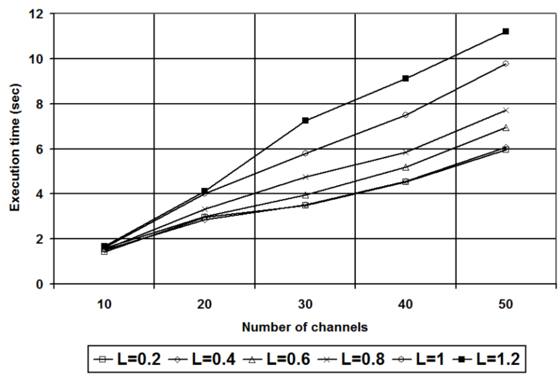

Fig. 5: The average execution time per connection request versus the number of available channels W per fiber.

tests we also observed that the average length of the lightpaths is decreased from 457 km to 415 km, when the load L is increased from 0.2 to 1.2. This is because when the load offered to the network is increased, then the impact of physical impairments (and in particular, that of the interference among lightpaths) becomes more severe and therefore the IA-RWA algorithm tends towards selecting shorter feasible lightpaths. Fig. 6 depicts the distribution of channel usage for traffic load of 0.2 and 1.2. We can observe that the IA-RWA engine uniformly utilizes the available channels per fiber (i.e., W=10). Additionally, in order

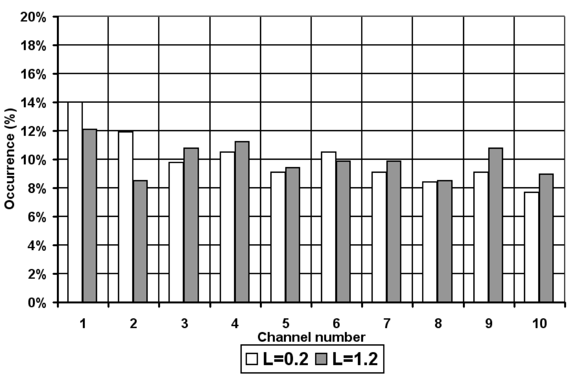

Fig. 6: Distribution of channel usage.

to quantitatively evaluate the performance of MP IA-RWA engine, we fed the RWA solutions produced for different load values to the Q-Tool. The distribution of the Q-factor values for traffic loads 0.2 and 1.2 and 10 available channels per fiber (W=10) are shown in Fig. 7. The average Q value of the active lightpaths is 27.2 and 25.7 dB for loads 0.2 and 1.2, respectively. We can also observe that by increasing the traffic volume the distribution of the Q-factor values is skewed towards lower quality. However all the active lightpaths have a guaranteed Q value, above the 15.5 dB threshold.

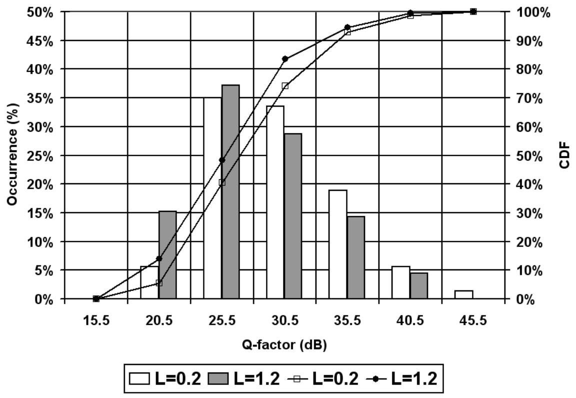

Fig. 7: Distribution of Q-factor (W=10).

Conclusions

We presented a network operation tool called Impairment Aware Lightpath Computation Engine (IALCE) that is able to support optical networks with different topology, load and physical characteristics. Our simulation results validate both the efficiency of IALCE, in terms of connection success ratio, the quality of established lightpaths, and its fast operation, as demonstrated by its average execution time per connection request.

Acknowledgments

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