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Experimental Comparison of Impairment-Aware RWA Algorithms in a GMPLS-controlled Dynamic Optical Network

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Abstract: The European research project DICONET proposed and implemented a multi-plane impairment-aware solution for flexible, robust and cost-effective core optical networks. The vision of DICONET was realized via a set of cross-layer optimization algorithms designed to serve the network during planning and operation. The cross-layer modules were incorporated in a common software platform forming a planning and operation tool that takes into account physical-layer impairments in the decision making. The overall solution relies on a GMPLS-based control plane that was extended to disseminate the physical layer information required by the cross-layer modules. One of the key activities in DICONET concerns the routing and wavelength assignment of traffic demands that arrive dynamically during the network operation. Identifying the important role of dynamic lightpath provisioning, in this work we focused on the performance of routing algorithms in dynamic optical networks. We tested the suitability and performance of two different online IA-RWA algorithms in a 14-node experimental test-bed that employed centralized control-plane architecture under the same network and traffic conditions. The parameters used to evaluate the two routing engines included the lightpath setup time and the blocking ratio in a traffic scenario where connections arrive and depart from the network dynamically. Results for different traffic loads showed that optimum impairment-aware decisions are made at the expense of higher lightpath setup times.

Keywords: Networks; Optical Communications.

1. Introduction

Wavelength-routed optical networks that take into account the Quality-of-Transmission (QoT) have been proposed by the research community in order to achieve high-performance end-to-end connectivity and cope with the unprecedented growth of Internet traffic [1]. Impairment-Aware Routing and Wavelength Assignment (IA-RWA) algorithms have been developed, which given a specific connection demand find the optimum combination of a route and a channel in terms of the optical signal QoT [2], [3]. In addition, to support the QoT-aware lightpath provisioning, the Generalized Multiprotocol Label Switching (GMPLS) protocols have been enhanced to include various physical-layer related parameters [4]. In [5] we have implemented and tested QoT-enabled distributed and centralized control plane schemes that incorporate an IA-RWA engine, essentially realizing the vision of dynamic and impairment-aware networking solution.

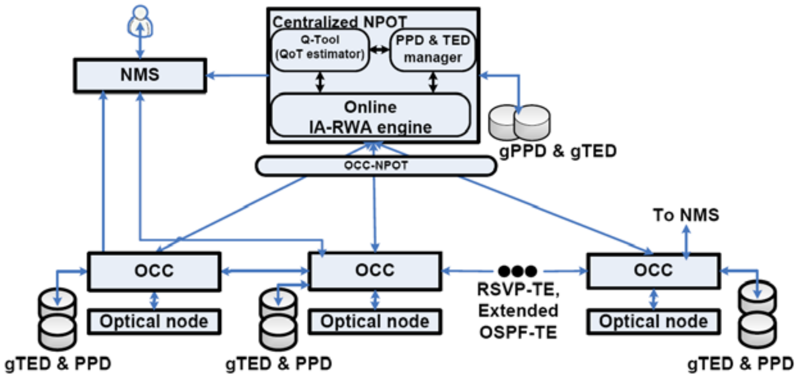

Figure 1: The centralized integrated scheme.

A multi-plane solution that spans from the transport plane to the control and management plane and incorporates all the aforementioned concepts has been the subject of the recently concluded European research project Dynamic Impairment Constraint Networking for Transparent Mesh Optical Networks (DICONET). In the framework of the DICONET project cross-layer modules were developed to tackle issues arising both in the planning (offline) and operation (online) phases of an optical core network. This work focuses on the performance of the IA-RWA engine under dynamic traffic conditions.

We consider herein a centralized scheme that integrates the routing engine in a unified extended GMPLS control plane (Figure 1). The online IA-RWA engine that resides at the core of this scheme is responsible for the route computation and the wavelength assignment for every new connection demand that arrives, always utilizing the available physical-layer information. Evidently the performance of the integrated solution relies highly on the performance of the QoT-aware routing engine. Although the IA-RWA algorithms are typically tested individually as a standalone module, it is the goal of this work to demonstrate their importance as part of an operational network platform, not only in terms of the blocking ratio but also in terms of the connection setup time. To achieve this, the 14-node experimental test-bed of DICONET was utilized to evaluate in turn two different IA-RWA algorithms under the same conditions. The results shown here demonstrate a trade-off between the setup time and the blocking ratio of the two employed IA-RWA algorithms.

2. QoT-aware Routing Engines in the Centralized Control Plane

An important building block in the integrated test-bed (detailed in [5]) is a custom Network Planning and Operation Tool (NPOT), which at operation mode encompasses all the modules necessary for the dynamic connection provisioning, i.e. the routing engine, the QoT estimator and a database manager. The QoT estimator is responsible for the signal quality assessment by utilizing the global Physical Parameters and Traffic Engineering Databases (gPPD and gTED). The two databases essentially carry all the real-time information that is required for the computations of the IA-RWA and the QoT estimator, including the network topology, the physical-layer status and the wavelength availability.

As depicted in Figure 1 the lightpath computation process is performed by a single NPOT that communicates with all the optical nodes of the network thus providing a centralized point of control. The control plane is composed of a set of 14 Optical Connection Controllers (OCCs) each corresponding to a network node. The OCCs employ the full GMPLS protocol suite, including standard RSVP-TE and extended OSPF-TE [5]. The two protocols are responsible for the lightpath establishment and the proper update of the global and local databases. Each OCC node controls the respective Optical Cross Connect (OXC) emulator through the Connection Controller Interface (CCI) (Figure 2). The set of OXC emulators form the emulated transport plane.

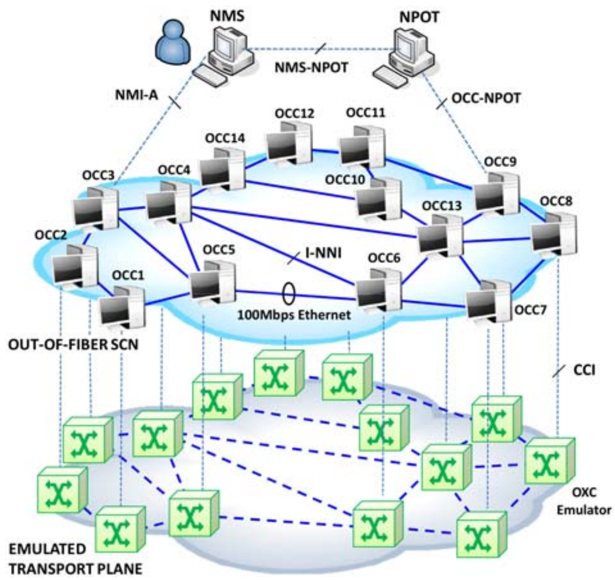

Figure 2: The experimental test-bed.

Upon the arrival of a new demand, the source node OCC is notified by the Network Management System (NMS) to initialize the lightpath request process. In turn, the request is forwarded to the online IA-RWA engine, through the OCC-NPOT interface. The IA-RWA engine accesses the databases to get an update of the available resources and consults the QoT estimator to make an impairment-aware decision. In [5] the centralized scheme used as routing engine the Multi-Parametric IA-RWA algorithm (MP) [3]. Important rationale for the initial selection of this algorithm was the need for an engine that can respond fast to a given connection demand. Typically the bottleneck in the path computation is located in the QoT estimation. Indeed the QoT estimator utilized here (Q-Tool) [6] estimates the joint impact of the dominant physical layer impairments (PLIs) in a method that combines analytical models and numerical simulations. Given the computational intensity of the QoT estimator the MP algorithm was designed so as to avoid the Q-Tool invocations whenever possible. It utilizes a multi-cost routing approach that includes impairment generating sources to indirectly account for the physical layer degradations. In this way it efficiently allocates the network resources while keeping the execution times low. The performance of the MP algorithm in terms of the blocking ratio depends highly on the weights assigned to the various impairment generating sources. The exact values of these weights are selected during a training period.

Herein the MP algorithm is compared to an IA-RWA engine whose primary goal is to return optimum lightpaths in terms of QoT. The algorithm in question refers to an IA-RWA heuristic named Rahyab and presented in [2]. The algorithm that was initially designed for planning and featured also path-protection capabilities, was properly adapted for online operation (further denoted as OR). Given a connection request, OR, constrained by the wavelength continuity and the channel availability, searches among all possible lightpaths (for *k*-shortest paths) to find the one that yields the best QoT both for the new connection but also for the already established ones. Essentially it decomposes the network topology into *W* planes, where *W* is the number of channels per link, and computes k shortest paths for each of the planes. Consider for instance that *W* is equal to 10, *k* is equal to 3 (*k* is an input parameter of OR) and all 3 computed shortest paths are available end-to-end in all planes. Then OR forms a pool of 30 candidate lightpaths and invokes the QoT estimator for each of them separately to assess them in the presence of the established lightpaths. The optimization benefit of this algorithm comes with a cost in execution time

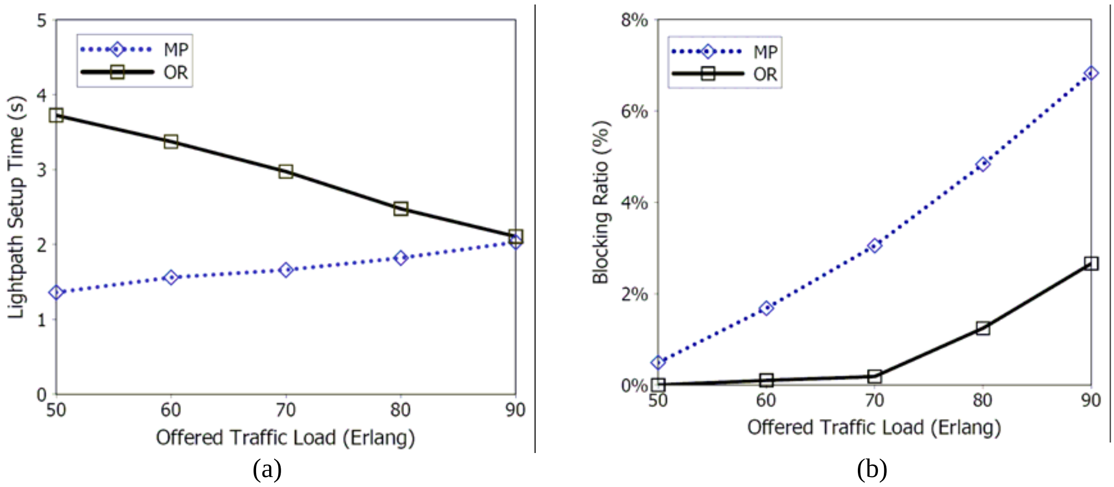

Figure 3: (a) OR yields longer connection setup times that tend to improve for more loaded traffic scenarios, (b) MP leads to higher blocking ratios than OR that makes optimal impairment-aware decisions.

as it requires the consecutive execution of the QoT estimator several times for each connection request.

3. Results

Thanks to the modular design of the centralized NPOT, the MP QoT-aware engine was replaced in the test-bed with the OR engine in order to evaluate and compare OR to the MP algorithm. The 14-node experimental test-bed represented the same topology as the nation-wide backbone network of Deutsche Telekom (DT) (Figure 2). The DT topology consists of 46 unidirectional links and it was assumed that each link is able to carry 10 optical channels. The offered traffic was generated by uniformly distributed connection requests to all network nodes following a Poisson process. The load was determined by assuming connection holding times (HTs) exponentially distributed with mean 600s and by decreasing the connection inter-arrival times (*load=HT/IAT*). The resulting load ranged from 50-90 Erlangs with a step of 10. The two algorithms used the same QoT estimator.

Recognizing the importance of setup time in the online dynamic connection provisioning process, we measured the time it takes for a connection to get served and established at each of the aforementioned scenarios. In particular Figure 3 (a) shows the setup time averaged over the 10K connections for both algorithms and includes the delay of the IA-RWA routing and QoT estimations as well as the signalling that takes place by the control plane, following the successful lightpath computation. In case of unacceptable QoT or lack of resources a demand gets blocked. For reasons of completeness we also computed the resulting blocking ratio of the two algorithms (Figure 3 (b)).

As shown in Figure 3 (b), OR outperforms MP in all traffic scenarios, yielding a blocking ratio lower than 3% for 90 Erlangs. Apparently, OR takes full advantage of the QoT information and manages to make optimal impairment-aware decisions. Nonetheless its benefit is counterbalanced by its performance in terms of time. Figure 3 (a) shows that OR requires more than twice the time of MP to serve and establish a lightpath for traffic load of 50 Erlangs. MP makes faster decisions that in the case of the lower traffic assumed (50 Erlang) is also coupled by low blocking ratio that may be further improved with better selection of the weights of the impairment-generating sources. As the load increases though, OR demonstrates improved setup times, almost reaching the setup time of MP for 90 Erlangs. As mentioned before, OR selects a lightpath among the set of all possible lightpaths, on the grounds of QoT. As the load increases more network resources are occupied, leading to less possible candidate lightpaths and therefore less QoT estimations. As a consequence the execution time shortens resulting in improved setup delays.

4. Concluding Remarks

The consortium of the DICONET project envisioned and planned a comprehensive solution to address the challenges of a core optical network. The project that recently concluded its activities, successfully implemented the vision of a GMPLS-controlled, dynamic and impairment-aware network. Cross-layer optimization modules were developed to serve the offline and online phases of a network and the standard control plane protocols were properly enhanced to disseminate the valuable physical layer information.

This work demonstrated the significance of the online routing strategy in the context of dynamic impairment-aware networking. Focusing on the performance of the IA-RWA algorithms inside an operational network, we compared two such algorithms, namely MP and OR, in a 14-node experimental test-bed using a centralized impairment-enabled control plane, under the same network and traffic conditions. On the whole the results indicated that the IA-RWA algorithms make optimum impairment-aware decisions at the expense of higher lightpath setup time. In terms of the lightpath setup time MP performed in general better in the considered scenarios. On the other hand, OR demonstrated lower blocking ratios and higher setup times that tend to improve as the traffic load increases. Indeed for the scenario with the highest traffic load considered (i.e. 90 Erlangs), OR seems to be a suitable choice as it prevents unnecessary blocked connections keeping setup times comparable to MP. Nonetheless, MP has the potential to improve its performance in terms of the blocking ratio by carefully selecting the weights of the impairment-generating sources while maintaining its inherent capability to deliver fast routing decisions.

Acknowledgements

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