# Dynamic Impairment-Aware Optical Networking: Some Experimental Results of the EU DICONET Project

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**ABSTRACT**

The paper presents some results from the experimental validation of the achievements of the EU DICONET project. Specifically, the DICONET test-bed is presented and the experiments conducted for the performance evaluation of the control plane approaches designed to include the Physical layer Information (PLI) in the Routing and Wavelength Assignment (RWA) problem are discussed.

**Keywords**: Optical transparent networks, Physical impairments, Network Planning and Operation Tool.

## 1. INTRODUCTION

The advances in optical transmission technology are driving the evolution from legacy opaque towards all-optical transparent networks. In transparent networks the optical signal is transmitted without electrical regeneration at the intermediate nodes. Although with full optical-electrical-optical (O-E-O) conversion the optical signal can be transmitted over longer distances, it increases the overall network cost due to the huge number of regenerators to be deployed. However, the evolution from opaque to transparent networks implies some challenges that must be properly addressed. In fact, in transparent networks, very long light-paths might be unfeasible due to the physical layer degradations that accumulate along the path. Electrical regenerators can be placed at selected nodes, increasing the total distance that the light-paths can traverse; these networks are referred to as translucent networks. Both in transparent and translucent optical networks, Physical Layer Impairments (PLIs) information must be taken into account in the Routing and Wavelength Assignment (RWA) algorithms, that is, performing Impairment Aware (IA)-RWA. The feasibility of the light-paths can be determined by properly considering the PLI information and utilizing for instance the Q-factor of light-paths, which is commonly used to measure the Quality of Transmission (QoT) [1].

The main purpose of the recently concluded EU Dynamic Impairment Constraint Optical Networking (DICONET) project [1] has been the design of a dynamic on-demand connection provisioning process for both translucent and transparent networks. Specifically, DICONET developed a dynamic Network Planning and Operation Tool (NPOT) which considers the impact of PLIs in planning and operation phase of optical networking. Network planning, which typically occurs before a network is deployed, is focused on how to accommodate a large set of demands to be processed at one time. In the network operation phase, the demands are processed upon their arrival and one at a time. The operation process must take into account any constraint posed by the current state of the deployed equipment.

The impact of PLIs on transparent [2] and highly dynamic optical networks [3] has received much attention (see for example [4]). Specifically, the work in [2] reported the result of a centralized integration scheme for transparent networks considering various PLIs. On the other hand, proper functionalities/extensions are missing in the existing GMPLS protocols to consider the impact of PLI information in the RWA process for the optical connection establishment. Two control plane integration schemes have been designed and assessed within the DICONET project, namely, the centralized and distributed (see [1] and [5]-[7] for more details). In the former approach, a centralized NPOT is responsible for the IA-RWA computation, while the Optical Connection Controllers (OCCs) run the GMPLS OSPF-TE protocol (properly extended to disseminate PLI and wavelength availability information), a standard RSVP-TE implementation and the interface to the actual optical nodes. A TCP-based communication protocol between the OCCs and the NPOT has been implemented for requesting IA-RWA path computations. The NPOT maintains and manages the global topology and physical parameters repositories. These repositories are named global Traffic Engineering Database and global Physical Parameters Database (gTED and gPPD), respectively. Upon the arrival of a new connection request, the source OCC contacts the centralized NPOT to request an impairment-aware light-path computation. The online IA-RWA module of NPOT utilizes the multi-parametric IA-RWA algorithm [8] for the route and wavelength assignment. The QoT of the light-path is checked through the QoT estimator module of the NPOT (i.e., Q-Tool module [1]) and the information stored in the gPPD and gTED databases. When the NPOT finds a light-path with guaranteed QoT (Q-factor value above a predefined threshold), the light-path is then established through the standard RSVP-TE signaling protocol.

 

In the centralized approach, the QoT estimation process, which is performed using the Q-Tool module, is quite complex and computationally intensive. This process (i.e., QoT estimation) introduces significant impact on the overall light-path setup time. Therefore, the DICONET project also considered a hardware-based acceleration approach for the QoT estimator. Specifically, a Field Programmable Gate Array (FPGA)-accelerated Q-Tool has been implemented in a Xilinx Virtex IV FPGA with an embedded processor and integrated into the DICONET test-bed (Fig. 1 right). The performance of the FPGA-based QoT estimator module has been reported in [9].

In the distributed approach, the OCCs run the GMPLS RSVP-TE signaling protocol, properly extended to allow the real-time collection of information of the PLIs [1] and the OSPF-TE protocol, which is properly extended for the dissemination of wavelength availability information. Each node in the network runs an instance of the NPOT, which is connected to an OCC via the NPOT-OCC communication protocol.

## 2. DICONET TEST-BED

This section introduces the DICONET test-bed where the experimental evaluation of both the centralized and distributed impairment-aware light-path provisioning approaches has been reported.

The DICONET test-bed consists of a configurable Signalling Communications Network (SCN) running over WSS-based Optical Cross-Connect (OXC) emulators (Fig. 1, centre). In this configurable SCN, OCCs are interconnected by 100 Mbps full-duplex Ethernet links, describing the same topology of the underlying transport plane. OCCs are deployed by means of Linux-based routers running over Pentium IV @ 2 GHz, so that each OCC implements the full GMPLS protocol set: RSVP-TE for signalling, OSPF-TE for routing purposes and Link Management Protocol (LMP) for resource discovery and failure management [1]. Each OCC is composed of three different modules, namely, the Link Resource Manager (LRM), the Routing Controller (RC) and the Connection Controller (CC). Essentially, the LRM module is responsible for the management of the resources available at the optical node through the Connection Controller Interface (CCI). Next, the RC module implements the OSPF-TE protocol used to advertise the state of the local output data-links to the rest of the control plane OCCs. This information is contained in the Opaque Link State Advertisements (OLSAs) that the OSPF-TE daemons in all OCCs exchange among them every time that a data link is allocated or released, and is used to populate the TED and PPD databases maintained by the NPOT [1]. Finally, the CC is responsible for the light-path set-up and tear-down. OCCs are interfaced to the local or centralized NPOT, depending on whether the distributed or the centralized approach is implemented [1]. Moreover, the centralized NPOT is also interfaced with the network management system (NMS) in order to inform the latter of possible failure situations.

Finally, the DICONET test-bed also included a transport plane composed of three optical nodes. Specifically, the three optical nodes are 2-degree Reconfigurable Optical Add & Drop Multiplexers (ROADMs) based on the Wavelength Selective Switching (WSS) technology. The three optical nodes were connected among them to form an optical ring through G.652-based optical fibres. Each ROADM has been equipped with one optical performance monitor, which is able to perform optical power measurements and Optical Signal-Noise Ratio (OSNR) measurements.

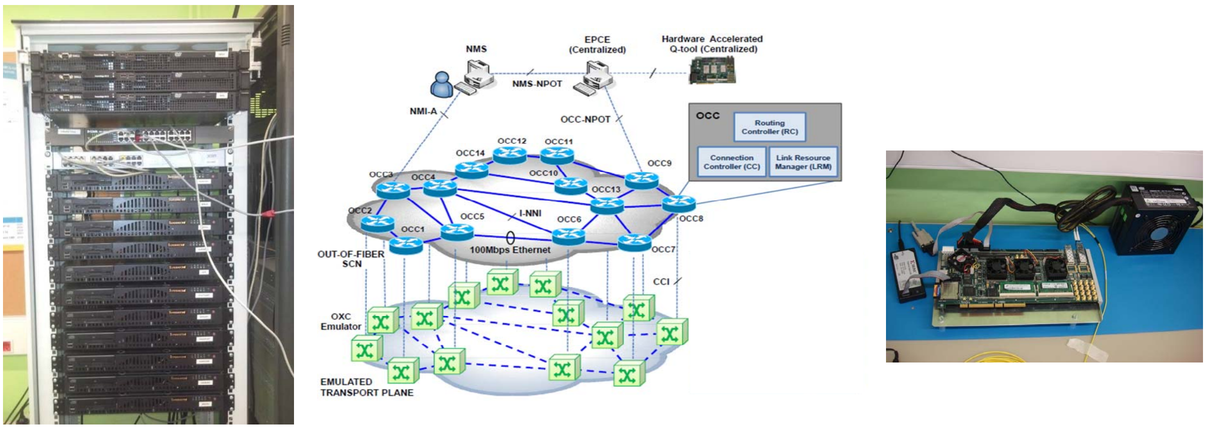


*Figure 1. DICONET test-bed: Control Plane (left); Experimental Network Topology (centre); FPGA board (right).*

### 2.1 Network Management System

The Network Management System (NMS) used in the DICONET test-bed was implemented separately and then integrated in the test-bed. In DICONET, we focused on Soft Permanent connection establishment. For this kind of connection, the NMS contacts the OCC for light-path establishment request and therefore, an interface between OCC and the NMS is required (i.e., NMI-A). Apart from the implementation of the different interfaces among NMS, Transport Plane (optical nodes) and Control Plane (OCCs), the NMS was provided with some additional functionalities, such as the network topology map, representation of detailed information about the current established light-paths (e.g., light-paths identifiers, Q-factor values of the optical connections, etc.). A Graphical User Interface (GUI) for the NMS has been implemented to depict the current status of the network. Some pictures of the GUI are shown in Fig. 2.

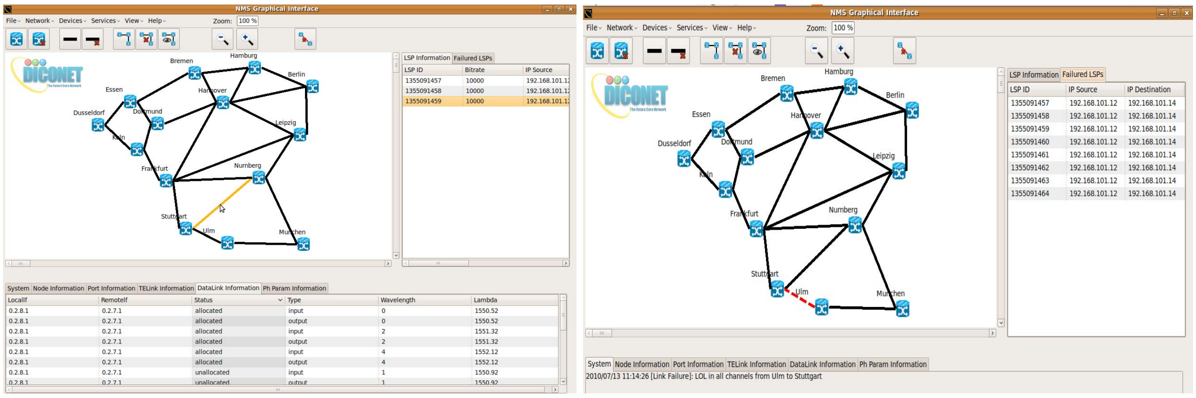

*Figure 2. DICONET Network Management System Graphical User Interface (GUI).*

## 3. EXPERIMENTAL EVALUATION

This section presents some of the experimental results obtained from the validation of control plane integration approaches over the DICONET test-bed. Throughout the evaluation, the light-path setup time has been taken as the main performance criterion. Additionally, the NPOT failure management capabilities have been also evaluated for the centralized approach.

In the first case study, light-path requests arrive to the network following a Poisson process and the requests are uniformly distributed. The light-path holding times (HTs) are exponentially distributed with a mean value of 600 seconds. Different loads are generated by adjusting the light-path inter-arrival times (IATs) accordingly (load = HT/IAT). Fig. 3 depicts the average light-path setup time in the network, depending on whether the Q-Tool in the NPOT is software-based (non-accelerated) or FPGA-accelerated. Fig. 3 also reports the setup times obtained by the impairment-aware distributed light-path provisioning approach [1]. It can be observed that FPGA-accelerated Q-Tool significantly decreases the light-path setup times. Interestingly, almost the same performance as in the distributed approach can be reached, especially for low offered loads. Moreover, even though the light-path setup times are increased with the offered load, such increase is not as pronounced as in the case without acceleration. In order to better appreciate the improvements provided by the FPGA hardware acceleration, the different components of the light-path setup time (i.e., the waiting time at the NPOT scheduler, the NPOT processing time, the Q-factor computation time and the control plane signalling time) can be considered [6]. By using the FPGA-accelerated Q-Tool, the average Q-factor computation time is significantly reduced (on average, in the considered network scenario, a reduction about 82% has been achieved). Moreover, the Q-factor computation time also scales better with the offered load to the network, which becomes of crucial importance.

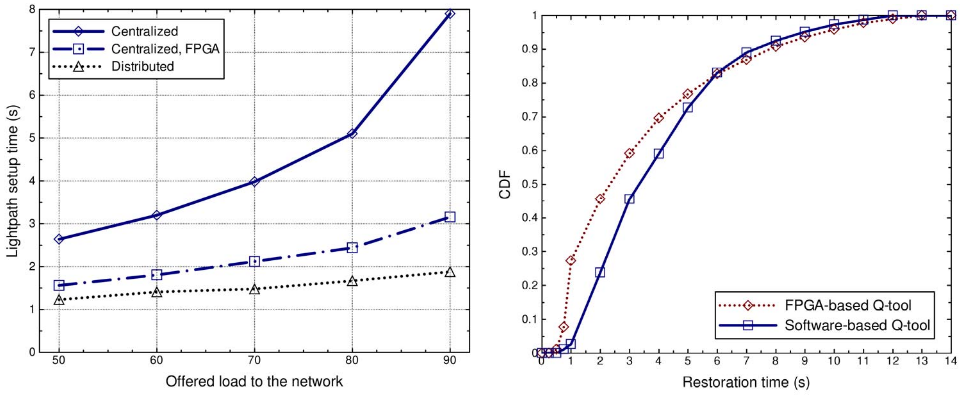


*Figure 3. Light-path setup time (left); Cumulative Distribution Function (CDF) of the light-path restoration time (right).*

In addition, experiments to assess the performance of the centralized light-path restoration function supported by the NPOT have been conducted [7]. The centralized NPOT implements a failure management module that is able to localize the link where the failure has occurred. This module is initially employed in the network planning phase to design an *m-trail* solution able to localize the failed link in the network [10]. Basically, a different code is assigned to each monitor in the network. Hence, based on the Loss of Light (LoL) alarms arising from a failure, which contain the specific monitor code, and the alarm code lookup table constructed during the *m-trail* design, the module can localize the exact failed link. As soon as the failure is localized, the NPOT informs the source node OCC of each affected (restorable) light-path in order to trigger the restoration procedures.

For the evaluation of this centralized restoration process, the network has been loaded with 10, 20, 30, 40 and 50 active light-paths between randomly selected node pairs. These connections have been considered to be restorable or 1 + 1 protected following a 70 – 30% restorable-protected ratio. Then, on each deployed network scenario, 10 independent failures were caused in randomly selected links. Fig. 3 (right) draws the Cumulative Distribution Function (CDF) of the light-path restoration time in the network. The results corresponding to the software-based Q-Tool and the FPGA-accelerated Q-Tool are plotted. Firstly, from the figure, it can be derived that, by using the software-based Q-Tool, 72% of the light-path restorations are performed within promising 5 seconds. However, as shown, the FPGA-accelerated Q-Tool leads to substantial restoration time benefits; in fact, in such case, around 30% of the restorations are performed below 1 second.

Finally, the experimental studies conducted over the deployed field-trial (including the three optical ROADMs) successfully demonstrated the proper interworking/interoperability among the different hardware and software modules developed inside the project.

## 4. CONCLUSIONS

A key contribution of the EU DICONET project has been the design and development of a physical layer impairments aware network planning and operation tool (NPOT) that resides in the core network nodes and that incorporates the performance of the physical layer in both planning and operation network decisions. In order to realise the vision of dynamic impairment-aware networking, an integrated scheme spanning from the optical transport plane up to the management plane was considered. With such purpose in mind, the DICONET project designed and implemented an impairment-aware GMPLS-based control plane to be incorporated into the network, which enhances the network operation with dynamic impairment-aware connection provisioning and recovery capabilities. From the experimental results, it can be derived that the DICONET approaches for IA-RWA are suitable to be deployed in future all-optical networks.

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