Photonics in Switching in NoE e-Photon/One+

Carla Raffaelli*, Lena Wosinska†, Nicola Andriolli**, Franco Callegati†, Piero Castoldi†
Wojciech Kabacinski†, Guido Maier†, Achille Pattavina†, Luca Valcareghni†

* D.E.I.S. – University of Bologna, Viale Risorgimento, 2 – 40136 Bologna, Italy
† The Royal Institute of Technology KTH, School of ICT, Electrum 229, 164 40 Kista, Sweden
** Scuola Superiore Sant’Anna - Pisa, Italy
† Poznan University of Technology, Poland

ABSTRACT

The exploitation of photonic technology through application of switching principles and system concepts in switch implementation, i.e. photonics in switching, is a very challenging topic in the field of optical networking research. Many European research teams have been involved in high quality studies and trials in this field since several years and obtained funding opportunities for joining their expertise within the e-photon/One+ Network of Excellence. This talk aims at presenting how collaborations on photonics in switching research has been organized within e-Photon/One+ and which actions have been finalized for exploitation and dissemination of this knowledge in science and education. The paper will report a description of research contributions from different partners involved in photonics in switching research.

Keywords: Optical networking, Optical switching, Switching technology.

1. INTRODUCTION

Photonic technology has experienced in the last decade significant developments that make it appealing for a wide range of services and applications, also confirmed by the increasing interest of companies in this field [1]. Optical networking is the context where optical technology represents the best candidate to support the high bandwidth demand of future communication networks [2]. Different network models can be applied to exploit the optical technology in communication networks. The optical circuit-switching paradigm (at either fiber or wavelength level) is a technique to offer huge bandwidth at the backbone level. This approach provides access to bandwidth with a very coarse granularity and therefore with limited bandwidth management capability and flexibility. Optical Burst Switching (OBS) and Optical Packet Switching (OPS) [3], [4] are, respectively, a medium and a longer term networking solution, promising more flexibility and efficiency in bandwidth usage combined with the ability to support different services [4], [5].

Implementation of different network models is strictly related to available technology for component and system implementation. New professional figures working in this field should know both systems and technology aspects to cope with the complex task to design next generation networks.

With this consideration in mind a Common Master program has been defined for education in Optical Networking throughout Europe in the framework of the e-photon/One+ Network of Excellence, funded by the European Community in the years 2004 – 2008. The Common Master is organized in several modules that fit into the regular credit based education system. Contents of the master are strongly based on recent research results in optical networking coming from involved partners.

This paper is based on the material which contributes to one of the courses of the Common Master program and reflects the main research advances in the area of Photonics in Switching. In figure 1 the main components of this research are sketched and their reciprocal relationships outlined by overlapping areas.

The objective of the course is to offer students an opportunity to learn about emerging switching techniques and technologies for optical networks, to show principles of photonic circuit switching, burst switching and...
packet switching and to give an overview of the WDM network elements, optical packet switching nodes and emerging technologies. The success of powerful and optimized switch design is strictly related to integration of knowledge in the overlapping region of figure 1.

The paper is organized as follows. In section 2 the optical network elements are reviewed. In section 3 a reference to OXC architectures and scheduling algorithms is given. In section 4 some design methodologies and guidelines for optical packet switches are discussed. In section 5 the relationships between node and network design are presented. Finally, conclusions are given in section 6.

2. OPTICAL NETWORK ELEMENTS

As mentioned in the introduction three optical network models can be mainly considered, i.e. optical circuit switched OCS networks, optical burst switched OBS networks and optical packet switched OPS networks. Network elements are the building blocks for each kind of network. Due to the differences in functionality between OCS, OBS and OCS different network elements are employed to perform the major functions in each of them [5].

2.1 Optical Circuit Switching

OCS networks provide end-to-end optical channels (lightpaths) between network nodes and are referred to as wavelength-routing networks. Lightpaths are set up and torn down on request from the users. Consequently, OCS networks consist of optical line terminals OLTs, optical line amplifier OLA (or regenerator), optical add-drop multiplexers OADMs and optical cross-connects OXCs interconnected via fiber links. OLTs are relatively simple network elements. They provide multiplexing and demultiplexing wavelengths at the end of point-to-point links. OLTs mainly consist of transponders to adapt to the optical channel and wavelength multiplexers.

OADMs are used when a small fraction of the WDM signal needs to be dropped at the node and the main part passed through and in this way can contribute to better resource utilization in the network. There are a number of OADM architectures such as parallel with a number of channels separated (using AWG-filters), serial where a single channel, SC-OADM, is dropped per stage (using Bragg gratings) and band drop where a band of wavelengths are dropped and further separated. OADM can be either static (carefully planning is needed) or reconfigurable (ROADM). ROADM are able to dynamically select the wavelengths to be dropped and added.

Finally, OXC are the key elements enabling reconfigurable optical networks. As compared with an OADM, the OXC is advantageous for complex mesh networks and/or a large number of wavelengths. In Section 3 selected architectures of OXCs are presented. OXCs can perform several key functions in OCS networks such as automated lightpath provisioning, protection, wavelength conversion, multiplexing, etc. Due to this functionality and to the huge traffic volume handled by OXCs reliability of this network element is of great importance. Providing 1+1 redundancy for an OXC can be very expensive since it would require duplicating the whole switching node. Therefore, OXC architectures with inherent redundancy have been proposed in [6].

2.2 Optical Burst Switching

Compared to OCS network OBS is based on statistical multiplexing, which increases the efficiency of network resource utilization. The main advantage of the OBS network compared to OPS network is that no optical RAM memory is needed. OBS networks mainly consist of three types of network elements, namely OBS ingress, egress and core nodes. The ingress routers aggregate client data (e.g., IP packets) into large bursts. Each burst is associated with a control packet (or header). In the OBS network the control packet (or header) is processed electronically at each core node. The main functions performed at the ingress node are: optical burst assembly and generation, offset-time decision and burst size decision. At the egress node the data burst is disassembled. The OBS core nodes perform control packet (header) lookup, optical cross-connecting and data burst monitoring. The ingress and egress nodes are typically electronic routers with optical interfaces while the core nodes are OXCs with a control plane.

2.3 Optical Packet Switching

OPS networks consist of OPS nodes. The functionality of an OPS node includes: decoding of packet header, (can be electronic if the packet header is encoded at lower bit rates), setup a switch fabric (the reconfiguration needs to be performed very fast in ns range), synchronization (for synchronous OPS nodes), multiplexing, and congestion resolution. A major obstacle faced in building all-optical packet switched networks is the difficulty in implementing all-optical packet switching nodes and performing packet switching in the optical domain. So far optical buffers use to be realized by fiber delay lines (i.e., not random access memories). Thus, the main limitation with state of the art technology for implementing all-optical packet switching nodes is the difficulty of building flexible optical buffers. Consequently it is difficult to obtain low packet loss probability and meet Quality of Service (QoS) requirements. Several approaches to solve the contention resolution problem in asynchronous OPS nodes have been proposed [7-9].
3. OXC ARCHITECTURES AND CONTROL ALGORITHMS

In OXCs changes in configured connections are usually done very rarely, making rearrangeable switching architectures interesting to implement this kind of optical switches [10]. However, when a new request arrives to an OXC, the connection should be done very quickly. Therefore, an appropriate control algorithm should select a connecting path through a switching fabric in a very short time. Several research in e-Photon/One+ concerns designing such control algorithms in photonic switching fabrics. One of such algorithm was proposed for multi-plane banyan type switching fabrics composed of 2x2 switching elements [11]. This algorithm can be implemented in different ways. One of its implementations enables to set up a new connection in O(1) time, while the state of the switching fabric is updated in the memory when the connecting path is being set up. This algorithm does not take into account the crosstalk which may occur when two different connecting paths use the same switching element. The modification of this algorithm has been proposed in [12] to avoid this first order crosstalk. This modified algorithm can also chose a connecting path in O(1) time, while appropriate updating take place when this connecting path is being set up.

4. ARCHITECTURES AND PERFORMANCE OF OPS/OBS NODES

OBS/OPS nodes are key systems for the implementation of all optical burst/packet switched networks and many different architectures have been proposed in literature [4], [5]. A critical aspect, intrinsically related to the statistical multiplexing nature of packet switching, is contention resolution, which arises when multiple packets contend for the same output resource. Time and wavelength domains are available to face this problem in optical packet switches and they are typically used as combined to achieve the required performance. Due to the uncomfortable way to implement optical buffers using fiber delay lines, much interest is for the wavelength conversion approach. Different wavelengths are used to encode packets for the same switch output fiber by means of tunable wavelength converters (TWCs), whose feasibility is widely reported in literature. As regards switch configurations relying on TWCs, many solutions have been considered in the past namely the shared per node (SPN) architecture, where a common set of wavelength converters is available for contention resolution inside the switch, and the shared per fiber (SPF) architecture, where wavelength converters are available on input or output fibers. Important works on performance modeling of buffer-less switch architectures based on TWCs have been developed within e-photon/One+ and recently published which show that a limited number of wavelength converters, possibly with limited range, can achieve the same performance as architectures completely equipped with full range wavelength converters both in synchronous and asynchronous environments [13], [14]. Proper scheduling algorithm is needed to control the optical packet transfer from the input to the output wavelength, possibly by applying contention resolution through wavelength conversion. The resulting packet loss rate depends on the capability of the algorithm to find a matching between the transfer requests and available output resources as shown in [13]. Finally, practical solutions, coming from the strong interaction and collaboration among technology and system experts, have been proposed showing the benefits of multistage implementations [14]. These practical solutions have been also tested with possible implementation of optical FDL queues [15].

Design of contention resolution in OBS and OPS networks takes into account many parameters: number of fibers, of wavelengths per fiber, of delays, quantity and type of wavelength converters, implementation of the scheduling algorithms. The role of these parameters has been investigated and simple engineering rules have been defined [16]. The basic idea is to compare system configurations equivalent in terms of scheduling capabilities. It has been shown that performance is a function of two parameters only: the number of delays and the channel degree. Among all the possible combinations of these two parameters the best performance is found when a little, but not null, number of delays (usually one delay) is used. This makes contention resolution in the time domain easy to be implemented even with the limited size FDL queue.

5. IMPACT OF NODE ARCHITECTURES ON NETWORK PERFORMANCE

Network performance and switching node capability are mutually related. In fact, the lightpath establishment in wavelength routed networks involves the problem of selecting a suitable path (routing) and the problem of allocating an available wavelength for the connection (wavelength assignment). Network nodes are switching elements with different nodal degree, that all-optically connect input wavelengths to output wavelengths, allowing lightpaths to pass-through. Network nodes are also equipped with a finite number of transponders accepting traffic from tributaries at a fixed wavelength (typically in the second transmission window, in the 1300 nm range) for ignition in the WDM trunks at a transponder-specific wavelength (typically in the third transmission window, in the 1550 nm range). The routing and wavelength assignment (RWA) is affected by edge node capabilities in terms of wavelength selection (i.e. the capability of tuning on any wavelength when a tributary flow is admitted as a lightpath into a WDM optical domain) as well as by the core node capabilities in terms of wavelength conversion (i.e. the capability of converting the wavelength of a lightpath into any other available wavelength) [17]. Network performance depends on the RWA problem solution that in turn is affected
by the network node capabilities. Trade-offs between the implementation of specific node capabilities and the corresponding attained network performance, in terms of blocking probability and link utilization. Specifically, whenever implemented at all network nodes (full-mode), wavelength selection is more beneficial than wavelength conversion. On the other hand, if selection capabilities or conversion capabilities are deployed just in a limited subset of nodes (sparse-mode), sparse wavelength selection is not as beneficial as sparse wavelength conversion. Indeed, only the connections admitted in nodes with wavelength selection can exploit this capability: the network can leverage wavelength selection if all the nodes are equipped with it. On the contrary, wavelength conversion provided in a node can be exploited by all the connections traversing that node. In this sense wavelength conversion is a shared facility, while wavelength selection is a node-peculiar facility [18].

6. CONCLUSIONS

In this paper the main research topics which contribute to Photonics in Switching curriculum are presented and referenced to recent achievements available in literature. This experience has shown how cooperation among different research groups significantly improve the global expertise and finalize resources on problems that involve both technological and theoretical aspects and need different kinds of competence and backgrounds, typically not available in a single group.

REFERENCES