Ultra-fast All-optical Interconnection Network
Fully Based on Modular Integrable Photonic Digital Processing

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Abstract: We present a modular architecture of an all-optical interconnection network capable of forwarding 160 Gb/s fixed-length packets. It uses photonic digital processing subsystems built combining a single integrable module which exploits cross gain modulation in a semiconductor optical amplifier.

Keywords: digital photonics, all-optical switching.

1. Introduction

High performance computing systems currently exploit electronic interconnection networks to achieve ultra-high bandwidth and low latency communication; however these solutions are approaching their fundamental limitations in terms of power, wiring density and throughput [1].

These issues may be overcome by utilizing optical solutions, which increase the transmission capacity by orders of magnitude, reduce power consumption, and enable data format transparency and electromagnetic field immunity. Several research efforts currently aim at using exclusively optics within the switching nodes, with the ultimate goal of realizing ultra-fast and integrable all-optical interconnection systems. All-optical processing, despite its limitations compared to advanced electronic processing, can be the most suitable paradigm for simple and ultra-fast processing, since it reduces the packet latency to the optical time-of-flight. The first step toward this goal is the realization of the basic photonic processing modules, i.e. the all-optical logic gates. These modules can be then combined to realize more sophisticated all-optical combinatorial networks aimed at performing the required node functionalities.

In this paper, we first describe the implementation of a Semiconductor Optical Amplifier (SOA)-based photonic processing module that can be used as a building block to carry out various node functionalities. In particular the scheme of an N-bit comparator is detailed. Finally the architecture of a crossbar-based interconnection network comprising the above mentioned subsystems is presented.

2. Basic module for photonic processing

All the photonic digital processing functions necessary for the full operation of the all-optical interconnection network can be achieved combining a basic module, consisting of an SOA where counter-propagating signals interact by means of Cross Gain Modulation (XGM). This block can carry out different logic functions depending on the input signal configuration. As depicted in Fig. 1, the XGM interaction between a low power signal $A$ acting as a probe and a high power signal $B$ acting as a pump allows to obtain the $A \text{ AND } B$ operation. If both signals $A$ and $B$ act as pumps on a third probe signal $C$, the implemented function is $\overline{A \text{ AND } B \text{ AND } C}$. If the third signal is a Continuous Wave (CW) or a pulse train in case of Non Return-to-Zero (NRZ) or Return-to-Zero (RZ) $A$ and $B$ signals respectively, the basic block supplies the $A \text{ NOR } B$ logic operation. Finally if $A$ acts as a pump on the same probe, $\overline{A}$ is obtained. The use of counter-propagating configurations simplifies the module architecture, avoiding optical filter stages and allowing the photonic processing independently of the signal wavelength in the whole C-band. Moreover ultra-fast and polarization-independent processing can be achieved with ultra-fast polarization-insensitive nonlinear SOAs commercially available, able to process signals beyond 160 Gb/s [2]. Finally XGM effect presents regenerative properties on the output signal, especially in terms of compression of the noise on the “one” level. In this way the penalty introduced by the module is extremely low (< 0.5 dB measured with 10 Gb/s labels) and cascaded configurations can be admitted.

Fig. 1. Basic module in four different input configurations that allow to obtain $A \text{ AND } \overline{B}$, $\overline{A} \text{ AND } \overline{B} \text{ AND } C$, $A \text{ NOR } B$, and $\overline{A}$.

Exploiting the above mentioned basic module, we successfully implemented the node subsystems required for a $2 \times 2$ all-optical node architecture working at 160 Gb/s [3], i.e., the label extractor, the contention detector and manager, the switching element, and the packet eraser. In [4] a
photonic combinatorial network was demonstrated, simultaneously providing contention resolution and switch control signals with a processing time of few tens of ns.

In addition, through the presented basic module, more complex logic functions, such as N-bit comparison were demonstrated [5]. With the N-bit comparator the address matching function can be extended from a bit-wise comparison to a multi-bit magnitude comparison, and different packet priority levels can be managed. Therefore this subsystem enables the implementation of switches larger than in [4] and supporting packet priorities. Fig. 2 reports the photonic comparator scheme for N-bit words and the simplified architecture for N=1. In both cases just the basic modules in Fig. 1 are used, with the exception of the OR logic gates implemented with an optical coupler, because the input signals cannot be simultaneously at the high level.

![Fig. 3. All-optical crossbar-based interconnection network architecture.](image)

4. Network architecture

In this section, we describe the overall network architecture that can be realized combining the photonic subsystems presented above. Several interconnection matrices [6] can be exploited combining 2×2 switching elements based on modules similar to the previously described ones, exploiting XGM in SOAs [3]. In addition each switching element includes a switch controller able to optically generate an optical gate lasting as long as the packet duration, which maintains the switch in the bar or cross configuration (depending on its high or low level) for the whole duration of the packet. The gate generation in the optical domain can be obtained as in [3], [7].

As shown in Fig. 3, we opted for the crossbar solution, due to its attractive properties: it is internally non-blocking, simple in architecture, and modular [8]. Yet, it is complex in terms of the number of crosspoints, that grow as the square of the input-output ports: to this regard, optical inte-

4. Conclusion

In this paper we have proposed a highly modular architecture of an all-optical interconnection network capable of forwarding fixed-length optical packets up to 160 Gb/s. It consists of different configurations of a single discrete element exploiting XGM in SOA, which realize various all-optical logic gates. We claim that the proposed solution is a suitable candidate for implementation as an integrated all-optical chip.

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References