SEVENTH FRAMEWORK PROGRAMME

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Abstract:

This document is the first deliverable of the WP25 "Optical Interconnect". This report contains the planned activities into the BONE project.

At the time of submission of this Deliverable there are thirteen partners involved in the nine joint activities that have been proposed in this work-package. Moreover, at least two mobility actions are planned during the two years of the project.

Keyword list:
Optical interconnect (OI), board-to-board OI, rack-to-rack OI, shelf-to-shelf OI, on-chip OI, energy efficiency, power saving, optical backbone

Disclaimer

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1. Executive Summary :

This document is the first deliverable of the work package “Topical Project on Optical Interconnect”. As the title of this deliverable says, this report contains the planned activities into the BONE project.

At the time of this Deliverable sixteen partners are willing to provide their expertise to WP25 and nine joint activities are proposed, currently involving thirteen partners. The topics covered by this WP will study the optical implementation of the interconnection systems inside high-performance switching/routing systems. The target is to develop the capability to design and optimize an optical backplane, finding the technology and architecture best-fitting system requirements.

2. Introduction

The main objective of the work package "Optical Interconnect" is to study the optical implementation of the interconnection systems inside high-performance switching/routing systems. This first deliverable defines the activities planned into this "Network of Excellence".

In Section 3, this report provides a list of the partners involves in the work package. In Section 4 an organization of the TP activities into different Tasks is proposed. Section 5 focuses on the description of the joint activities. Finally, the last section concludes this report.

3. Participants

There are thirteen partners, at the moment, who intend to collaborate to the Joint Activities (JAs) of this work package. Table 1 shows the list of participants involved in the JAs that have been currently proposed.

A detailed description of the joint activities is provided in Section 5.

Partner #	Member	Country
29	**PoliMI**	IT
2	TUW	AU
12	UC3M	ES
14	UPCT	ES
22	UoA	GR
23	UoP	GR
30	PoliTO	IT
32	UniBO	IT
36	TUE	ND
39	PUT	PL
41	KTH	SW
45	UCAM	UK
49	ERICSSON	UK

Table 1: Work package participants in the WP25 joint activities

4. Workpackage structure

The main goal of WP25 TP Optical Interconnects can be summarized by the following statement:

- This project studies the **optical implementation of the interconnection systems inside a high-performance switching/routing system**. The target is to develop the capability to design and optimize an **optical backplane**, finding the technology and architecture best-fitting system requirements

The accomplishment of project goals implies, in first place, sharing expertise and previous work among the involved partners.

The complementary visions of the participants on the main subject of the TP have been discussed and compared in a preliminary WP25 meeting held in Rome on January 2008.

This Topical Project has been organized in a layered structure, according to the outcome of such meeting. The structure is represented in Table 2.

Task #	Task	Topics	Period of activity
T1	Survey and requirements	Requirements (how to win competition with electronics)	M 13-24
		Technology survey	
		OI-solution survey	
T2	Rack-to-rack and Shelf-to-shelf	OI layer requirements/constraints, solution proposal, validation (theory, simulation, lab)	M 13-36
T3	Board-to-board	OI layer requirements/constraints, solution proposal, validation (theory, simulation, lab)	M 13-36
T4	Chip-to-chip and On-chip	OI layer requirements/constraints, solution proposal, validation (theory, simulation, lab)	M 13-36
T5	"BONE switch"	Architecture, modules, subsystems	M 25-36

Table 2. WP25 Topical Project structure

Task T1 (active in the first year of the TP) provides the basis for WP25 investigation, exploring literature in order to list and classify technologies and architectures proposed so far for optical interconnections “inside the box”. T1 also analyze the framework of requirements to optical interconnection systems when used to implement the backbone of high-performance network-switching nodes.

Tasks T2 to T4 (active for the whole TP duration) are defined according to a layered approach following an interconnection hierarchy mainly based on typical connection distance. This allows us to separate layers that have very different features under the OI point of view. Each layer is characterized by different requirements and constraints that matter for the OI implementation: link distances, port-density (pin-out / pin-in) limitations, transmission-line speed, bandwidth, optical-propagation impairments (loss, crosstalk, etc.), synchronization accuracy, skew, delays, jitter, heat dissipation, power/energy consumption, etc. Also, the type of traffic (packet or circuit, packet size distribution, source statistical characterization, etc.) may changes from layer to layer, being very much dependent on the locality of the communications.

This organization in Tasks should help in identifying, for each layer of the interconnection hierarchy, the OI-technology solutions best matching the topology and requirements and constraints typical of that layer. These solutions will be studied and defined in details by the Joint Activities (JAs) of the project that are related to each Task T2-T4.

The last Task T5 (active in the second year of the TP) will pursue the definition of a “BONE switch” model that can be proposed as reference model for OI design and optimization. Task T5 will integrate the outcomes of the various JAs related to Tasks T2-T4: based on the solutions proposed by the JAs, Task T5 will try to show how high-performance switches or routers can take full advantage of OI, in particular pointing out: scalability, power/energy-consumption awareness, advantage over the electrical counterparts.

5. Joint Activities

In the following the content of the JAs of WP25 is described in details.

There are few JAs (JA 1-4) specifically dedicated to the implementation of Tasks T1 and T5.

The other JAs are related to the optical interconnection hierarchy defined by Tasks T2-T4. Each of these JAs may span over one optical interconnection layer, as better clarified below.

5.1 JA1 Identification of requirements of the optical backplane

Participants: TUW, PoliTO, UniBo

Responsible person: Slavisa Aleksic (TUW)

Description :

JA1 will contribute to WP25 studies with a detailed analysis of requirements of the systems where the OI proposed solutions will be applied. The application targets are the high-performance network nodes that can more benefit from an optical implementation of the backbone subsystem. Such nodes may comprise switches, routers, digital or optical cross-connects, add-drop multiplexers, etc. with different number of ports and different data rates. In light of these requirements, JA1 will identify potential bottlenecks of “traditional” electronic interconnection systems, in terms of scalability towards upgraded performance required by the future networks.

Outcome of the joint research activity:

JA1 will provide an overview on the techniques and technologies available today in electronic switching systems to implement interconnections. It will then analyze possible limitations of these solutions in front of new requirements and show in which cases and how optics can offer a real competitive advantage to equipment providers

Targeted call for papers:

HPSR, OFC, ECOC, Optical Switching and Networking

Deadline:

Month 24

5.2 JA2 Survey on photonic technologies for optical interconnections

Participants: PoliMI, PUT, PoliTO

Responsible person: Guido Maier (PoliMI)

Description :

Technological and architectural solutions proposed by the project will be backed by analysis trying to answer the following questions:

- which optical technology and component choice is most appropriate for the implementation of a specific OI subsystem?
- how much does it scale/heat/cost?
- what is the actual advantage over the electronic counterpart?

Answering such questions will be based on an extensive and deep analysis of technologies and optical components available today and potentially useful for OI applications.

The overview will comprise:

- Optical technologies for short-range point-to-point connections
- Optical space- and wavelength-switching technologies supporting backplane applications
- Passive components providing interconnection between switching elements and fixed permutation functions

Components will be classified and compared considering typical performance parameters such as: insertion loss, switching speed, crosstalk, excess noise generation, polarization dependency, power supplied, dissipated power, switching energy, etc.

Availability on the market or stage of development will also be considered, as well as possibility of integration in large structures and fabrication yields.

Outcome of the joint research activity:

Survey on state-of-the-art photonic technologies and components potentially useful for OI applications.

Targeted call for papers:

HPSR, OFC, ECOC, Optical Switching and Networking

Deadline:

Month 24

5.3 JA3 Survey on optical interconnection architectures and solutions

Participants: PoliMI, TUW, PUT, PoliTO, UoP

Responsible person: Guido Maier (PoliMI)

Description :

This Activity will study and classify the highest-performance optical and opto-electronic interconnection architectures presented in scientific literature or commercially available, covering both communication and super-computing applications. These solutions will be analyzed to highlight the best features obtainable nowadays, that can be viewed as the benchmark for the OI architectures proposed in JA4. We will aim at the identification of the constraints and the opportunities for the OI in the considered scenarios, as well as the different types of solutions proposed for the various application scenarios. OI architectures developed for computing applications will be considered despite the fact that WP25 is mainly oriented to networking systems: this is due to the large degree of advancement that OI has reached in that field nowadays.

Outcome of the joint research activity:

The main outcome of the activity will be a careful description and characterization of the most advanced best-performing optical and electrical interconnection systems presented in literature and commercial available. Possibly, experts from the industry (from the teleocm and/or computing areas) will be invited to present their vision on future developments of the OI technology.

Targeted call for papers:

HPSR, OFC, ECOC, Optical Switching and Networking

Deadline:

Month 24

5.4 JA4 The "BONE switch": a reference architecture for the optical backplane

Participants: UPCT, PoliMI, PUT

Responsible person: Pablo Pavon (UPCT)

Description :

While the JAs of Tasks 2,3 and 4, are dedicated to study optical interconnection solutions “inside the box”, this Activity (starting in the second year of the Project) will provide coordination and integration by fully defining “the box”. That is, building upon the experience of the on-going JAs of the three Tasks dedicated to the three levels of interconnection, partners involved in JA4 will fully collaborate to create a reasonable reference model which would represent the “ideal” application scenario for OI. Effort will be made to include all OI levels, from the optical backbone to the on-chip interconnections.

This “all-optically-interconnected” network node will be described as an open model, considering various hypotheses regarding its final utilization (as a switch or a router or a cross-connect). Moreover, it will be architected in a modular way, trying to point out its features of scalability and energy efficiency and its ability to comply with the system requirements defined by JA1.

Surely, despite the openness feature of the model, some decisions about technological and dimensioning issues will be taken: this will require shared expertise from all the participants to the JA and agreement with the other partners of the Topical Project. This is the main challenge that awaits this JA.

Outcome of the joint research activity:

Expected outcome is the definition of a future high-performance network element which is able to take full advantage of OI at all interconnection layers in order to overcome limitations of current top-line switches and routers, still based on electronic interconnection.

This JA will integrate and coordinate the results of the other JAs of WP25 by identifying a next-generation open model able to achieve breakthrough targets in terms of scalability and power/energy-savings.

Targeted call for papers:

Position paper on a major Magazine (e.g. IEEE Communications Magazine)

Deadline:

Month 36 (starting from Month 24)

5.5 JA5 Performance and complexity analysis of optical switching fabrics

Participants: PoliTO, PoliMI, UniBo, TUW, UPCT, UoP

Responsible person: Fabio Neri (PoliTO)

Description :

This Joint Activity is aimed at studying and defining the role of optical technologies in the implementation of switching fabrics for future high-performance switching architectures. It has been already active in the first year of BONE as JA3 within WP14, and has been reallocated to WP25. The focus is on WDM optical interconnection architectures to be used as a forwarding backplane in future multi-Terabit packet switches. A generic reference architecture was defined, consisting in several transmitters and receivers (corresponding to switch linecards), tuning their optical output to reach other linecards on a packet-by-packet basis in a synchronous way. In this framework, several optical fabric architectures were considered in order to identify the most convenient way to provide optically full connectivity among linecards with minimum impact on the optical signal quality, so as to be able to scale as much as possible the switching capacity (aggregate bandwidth scalability).

Some candidate broadcast&select architectures in single-plane configurations were first considered within WP14, which however exhibited tunability and maximum port count limitations. This motivated to consider multiplane architectures, that require less wavelengths in the system (and therefore less tunability requirements at linecards), and also can reach higher bitrates by improving optical signal performance. In multiplane architectures, space multiplexing is exploited in addition to WDM through the concept of switching planes (by having the N linecards distributed in S switching planes) as an option to improve scalability. Some multiplane architectures were considered by using different approaches to divide information across the different available planes, i.e., in the space dimension.

A detailed comparisons of the physical-layer behaviour of three architectures was jointly performed, with contributions from PoliTO, PoliMI and UniBO, by proper modelling optical components, as reported in BONE deliverable D14.1. These architectures were scaled up in terms of number of input/output connections and of bitrate on each input/output connection in order to find the maximum possible aggregate capacity. Overall, aggregate capacities of several Tb/s are possible with optical components available today: this is a very positive result in the direction of a deeper penetration of optics into switching architectures.

Within WP25, multi-stage versions of the proposed architectures will be studied.

Regarding how much does the implementation of these proposals cost, a cost analysis is being carried on, starting from an estimation of the required number of components, of transmitter complexity and a more detailed cost model for optical component based on commercial or near-commercial devices.

Furthermore, an comparative assessment of the scalability of power consumption for the considered switching fabric architectures will be started within WP25, possibly in comparison with implementations of similar functionalities in the electronic domain.

Another approach carried out by TUW in WP14 was focused on scalability and performance of optical switching fabrics based on internally interconnected broadcast-and-select optical switching units. Simple analytical models that use data of commercially available devices will be developed and used to analyse scalability and feasibility of this structure. The results will be validated using numerical simulations. Additionally, dynamic effects such as transients in switching devices and the pattern effect will also be taken into account during simulations.

Outcome of the joint research activity:

JA5 will generate scalability figures for selected optical switching fabric architectures in terms of:

- Maximum aggregate switch capacity
- Relative cost/complexity
- Power consumption

These results will be published in technical papers.

Deadline:

Month 36

5.6 JA6 Optical backplanes utilizing microring resonators

Participants: UoA, UC3M, PoliTO, PoliMI

Responsible person: Antonis Bogris (UoA)

Description :

Micro-Ring (MR) resonators have been demonstrated as all-optical switches in several simple or more complex configurations. The switching is usually achieved by changing the spectral characteristics of the filter. An incoming signal which coincides with the wavelength of a resonant mode of the MR cavity is switched by either the change of the transmittance or the detuning of the mode, or both. Several techniques have been proposed for the efficient control of the transmission characteristics of the MR. In passive devices optical modulation has been achieved using the electro-optic effect in polymer free-carrier injection in silicon, all-optical switching using free-carrier injection in GaAs–AlGaAs, and electro-absorption induced wavelength switching and routing. The optical characteristics and thus the spectral properties of active MR resonators can be dynamically tuned by changing their refractive indices.

In the context of this activity, several microring resonator architectures based on different materials will be classified in terms of their potential to play the role of a building block of large capacity multifunctional optical cross-connects (OXCs). The criterion of classification is fast optical switching without neglecting cost and power consumption issues. The work that will be carried out by UoA and UC3M will be mainly numerical hoping that experimental work that could strengthen the numerical studies will be also carried out at a later stage.

Since microring resonators have a very different crosstalk behavior between the non-resonant (or “bar”) and the resonant (or “cross”) state (crosstalk is much larger in the former state), interconnection architectures based upon microrings must be designed in order to minimize the number of cross states traversed by an input/output connections. PoliTo and PoliMi, will study the number of cross and bar states needed in previously proposed interconnection architectures, so as to select a (possibly original) architecture that permits maximum scalability of the aggregate capacity of microring-based optical switching fabrics given the physical-layer behavior of current microrings and their expected evolutions.

Furthermore, the tunability of microrings resonance wavelengths (e.g., by thermal effects) can be complemented by the tunability of information sources (i.e., of transmitters sending information through the switching fabric) in order to reduce complexity and improve scalability.

Outcome of the joint research activity:

Joint publications in international conferences and journals.

Deadline:

Month 36

5.7 JA7 Hardware efficient optoelectronic switch fabric

Participants: UCAM, PUT, TUE

Responsible person: Jose Bernardo Rosas Fernandez (UCAM)

Description :

Optoelectronic space switch design is bounded predominantly by signal distortion, noise figure and crosstalk. As the connectivity of the space switch is scaled beyond 4 inputs however, the performance is expected to become extremely sensitive to the chosen architecture. This in turn has considerable impact on system level metrics such as power consumption, data integrity and control plane complexity. This activity will build on insights from recent test-bed studies into low physical layer complexity switch fabrics. Low numbers of semiconductor optical amplifier gates will be considered with a view to minimising power consumption while maintaining excellent optical transmission performance. Other photonic PIC structures will also be considered.

Outcome of the joint research activity:

The project will study the requirements for short reach interconnection in terms of connectivity, bandwidth, latency, power consumption and traffic. Contention will not be considered as this may be addressed by implementing edge buffering electronically in a sufficiently short reach system.

Switch architectures will also be studied to reduce complexity in control and packaging in ways which do not unacceptably compromise optical performance. Architectures will be considered in terms of the degree of blocking, numbers of planes and the efficient utilisation of photonic hardware.

The role of new quantum dot materials will be studied along side advanced integration architectures for realising increasing functionality on monolithic circuits. Routes to power efficient operation will be studied. Circuit elements will be devised and compared for efficient scaling from 4 input switches up to 32 input switches. Design studies will address optimum levels of photonic integration. Testbeds will be developed to explore the performance of the switches and architectures to be studied.

From the architecture point of view, we will evaluate switch circuits with the following figure of merits:

- Number of cascaded switch elements in a switch fabric
- Number of SOAs elements
- SOA input power and dynamic range (IPDR) vs. Q (SNR) of the switched signals
- Combinatorial properties
- Blocking, both rearrangeable and strict-sense and its importance in packet based networking
- Control algorithm complexity.

From the integrated circuit viewpoint, key figures of merit to be considered are:

- Number of fibre pigtails

• Power consumption for a given capacity
• Optical layer performance: crosstalk, penalty and by spurious reflections
Number and density of electronic pads
Number of waveguide crossings

Targeted call for papers:

Conferences: ECOC, OFC, Photonics in Switching
Journals: PTL, JLT, JON

Deadline:

Month 36

5.8 JA8 On-chip optical switching networks

Participants: PoliTO, PoliMI

Responsible person: Fabio Neri (PoliTO)

Description :

In the implementation of networks on chip, i.e., of interconnections between computing cores within the same chip, optical technologies can complement low-power electronics in sight of reduced energy consumption. Previous work done by PoliTO in collaboration with Columbia University showed that optical networks on chip (based upon microring resonators) can bring significant (up to 40 times) power savings with respect to the electronic counterparts due to less dependency on bit rate and distance. Alternative optical architectures for on-chip interconnections will be proposed in JA8, and assessed in terms of complexity, scalability and power consumption. Access schemes suited for these networks will be proposed. A methodology to compare optical and electronic on-chip interconnections will be defined, together with some application scenarios.

Outcome of the joint research activity:

Three main outcomes are planned for JA8:

- architectures for optical networks on chip based upon microring resonators
- protocols and access schemes suited for these on-chip networks
- approaches and scenarios to compare electronic and optical networks on chip

Deadline:

Month 36

5.9 JA9 Reliability and power consumption of optical interconnects

Participants: ERICSSON, KTH, TUW

Responsible person: Rebecca Chandy (ERICSSON)

Description :

JA9 will perform analyses and reliability studies of the various optical interconnect devices (e.g. VCSEL, MEMS etc) and architectures that can be used in next generation networks.

In particular, Ericsson's research in this activity will be in comparative study and review of limitations and challenges in various photonic device technology and new developments in devices and transmission (e.g. VCSEL, MEMS, etc).

KTH will contribute with reliability analysis of different OI architectures. Furthermore, in close collaboration with Ericsson UK, a reliability performance comparison will be devised for considered architectures based on different component technologies.

Additionally to the limitations concerning transmission and availability issues, also limitations related to power consumption will be taken into consideration. Power dissipation of various devices and subsystems for optical interconnections will be analysed by TUW and the results of this study will be used to determine scalability of different technologies and approaches.

Outcome of the joint research activity:

Joint publications and Joint project proposals

Targeted call for papers:

ICTON, OFC 2010

Deadline:

Month 36

6. Planned mobility actions

The following mobility actions are planned within WP25:

- Guido Maier from PoliMI will visit PUT, starting in May 2009, one week.
- Rebecca Chandy from Ericsson will visit UDE for one week either in May or July 2009, subject to availability of staff and resources at UDE.

7. Conclusions

Table 3 summarizes the JAs proposed so far within WP25 with the list of current participants. Other JAs can be activated any time in the course of the TP, if needed.

JA #	JA title	Partners involved
1	Identification of requirements of the optical backplane	**TUW**, PoliTO, UniBo
2	Survey on photonic technologies for optical interconnections	**PoliMI**, PUT, PoliTO
3	Survey on optical interconnection architectures and solutions	**PoliMI**, TUW, PUT, PoliTO, UoP
4	The "BONE switch": a reference architecture for the optical backplane	**UPCT**, PoliMI, PUT
5	Performance and complexity analysis of optical switching fabrics	**PoliTO**, PoliMI, UniBo, TUW, UPCT, UoP
6	Optical backplanes utilizing microring resonators	**UoA**, UC3M, PoliTO, PoliMI
7	Hardware efficient optoelectronic switch fabric	**UCAM**, PUT, TUE
8	On-chip optical switching networks	**PoliTO**, PoliMI
9	Reliability and power consumption of optical interconnects	**ERICSSON**, KTH, TUW

Table 3. WP25 Joint Activities

Task #	Task	Topics	Timing	Joint activities fitting into the task
T1	Survey and requirements	Requirements (how to win competition with electronics)	1-12	JA1
		Technology survey		JA2
		OI-solution survey		JA3
T2	Rack-to-rack and Shelf-to-shelf	OI layer requirements/constraints, solution proposal, validation (theory, simulation, lab)	1-24	JA5, JA6, JA7, JA9
T3	Board-to-board	OI layer requirements/constraints, solution proposal, validation (theory, simulation, lab)	1-24	JA5, JA6, JA7, JA9
T4	Chip-to-chip and On-chip	OI layer requirements/constraints, solution proposal, validation (theory, simulation, lab)	1-24	JA8, JA9
T5	"BONE switch"	Architecture, modules, subsystems	12-24	JA4

Table 4. WP25 Tasks and related Joint Activities

Table 4 shows the correspondence between JAs and Tasks.

The proposal of joint activities and their research criteria adequately cover all the planned research objectives for this work package indicated in the BONE technical annex. If these planned activities follows the steps described in their proposal, this work package will fulfill the objectives defined in the project proposal.

Publications in international conferences and journals are almost assured thanks to the amount of partners and their expertise. Moreover, mobility actions, which will be carried out into this work package, will increase the interaction among the research groups involved in the work package, which is a secondary objective of this Network of Excellence.