Design Space Exploration of Optical Interfaces for Silicon Photonic Interconnects

Olivier Sentieys, Johanna Sepúlveda, Sébastien Le Beux, Jiating Luo, Cedric Killian, Daniel Chillet, Ian O 'Connor, Hui Li

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Olivier Sentieys[1], Johanna Sepúlveda[1], Sébastien Le Beux[2], Jiating Luo[1], Cedric Killian[1], Daniel Chillet[1], Ian O'Connor[2] and Hui Li[2]

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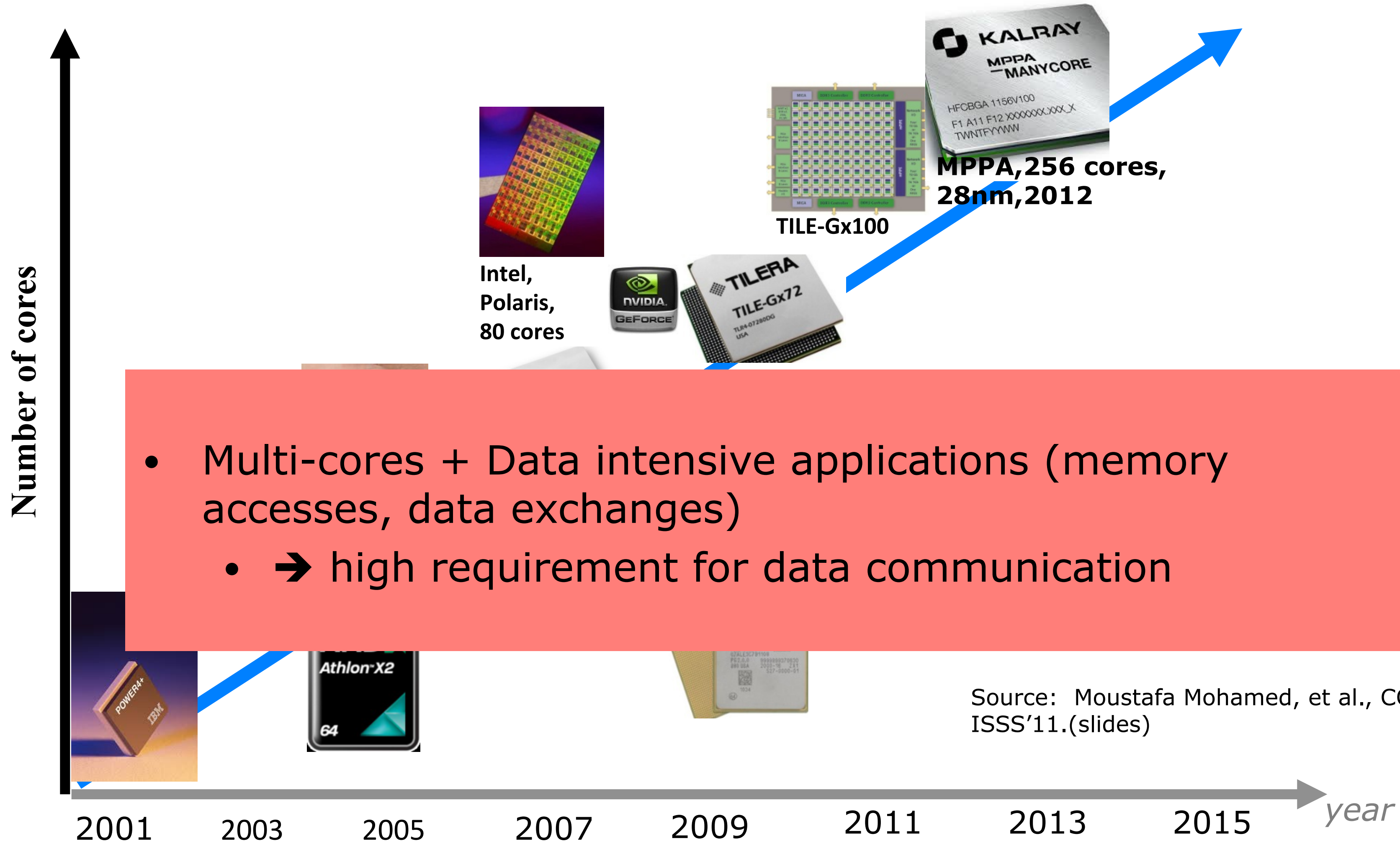
Context: Evolution of the number of cores



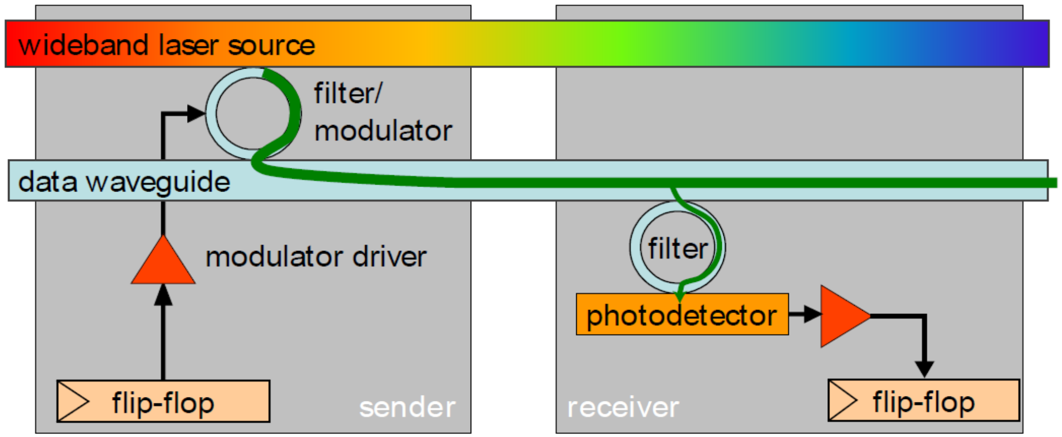
- Multi-cores + Data intensive applications (memory accesses, data exchanges)
  - ➔ high requirement for data communication

Source: Moustafa Mohamed, et al., CODE-ISSS'11.(slides)

Challenges: higher **performances**, higher **power efficiency**, higher **integration**

Context: Optical interconnect

- Multi-cores + Parallel applications + memory needs + …
  - ➔ high requirement for data communication
  - Classical NoC ➔ bottleneck !!
  - Need for more efficient communication infrastructure
    - Optical NoC could be a solution



Source: G. Kurian, et al., PACT, 2010

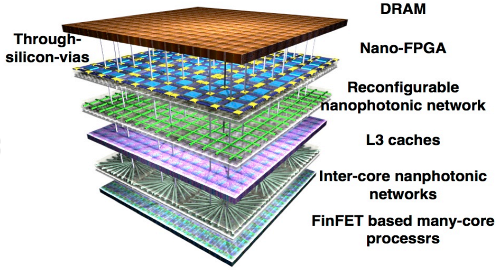
- Silicon Photonics
  - High throughput: Wavelength Division Multiplexing, WDM
  - Lower dynamic energy
  - Lower latency

- We need design space exploration, in particular for Optical interface !!

Context: Needs for Design Methodologies

Easily programmable and power efficient processors

```
#INCLUDE <STDIO.H>
INT MAIN()
{
    PRINTF("HELLO, WORLD !");
    RETURN 0;
}
```



Key
D
meth

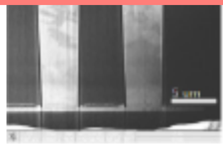
Focus of Design Space Exploration for 2 parts of the interface

- channel allocation
- laser power management

Key enabler: Emerging technologies

DGFET

Silicon photonics

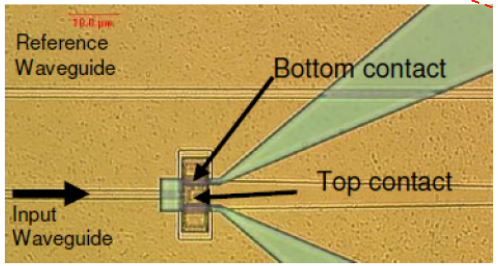


3D

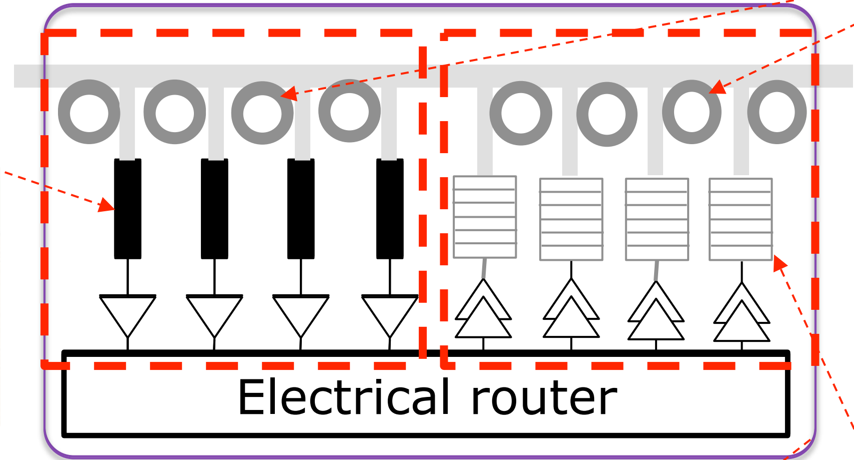
Outline

- Context and problematic
- **DSE of waveguides and wavelengths allocation**
- DSE of laser power management
- Conclusion

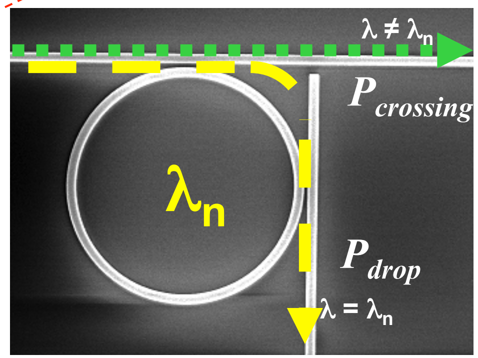
Silicon Photonics Interconnects



L. Vivien et al.,
Optics Express, 17, 6252 (2009)

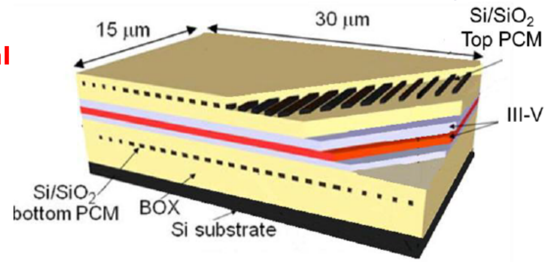


Micro-resonators

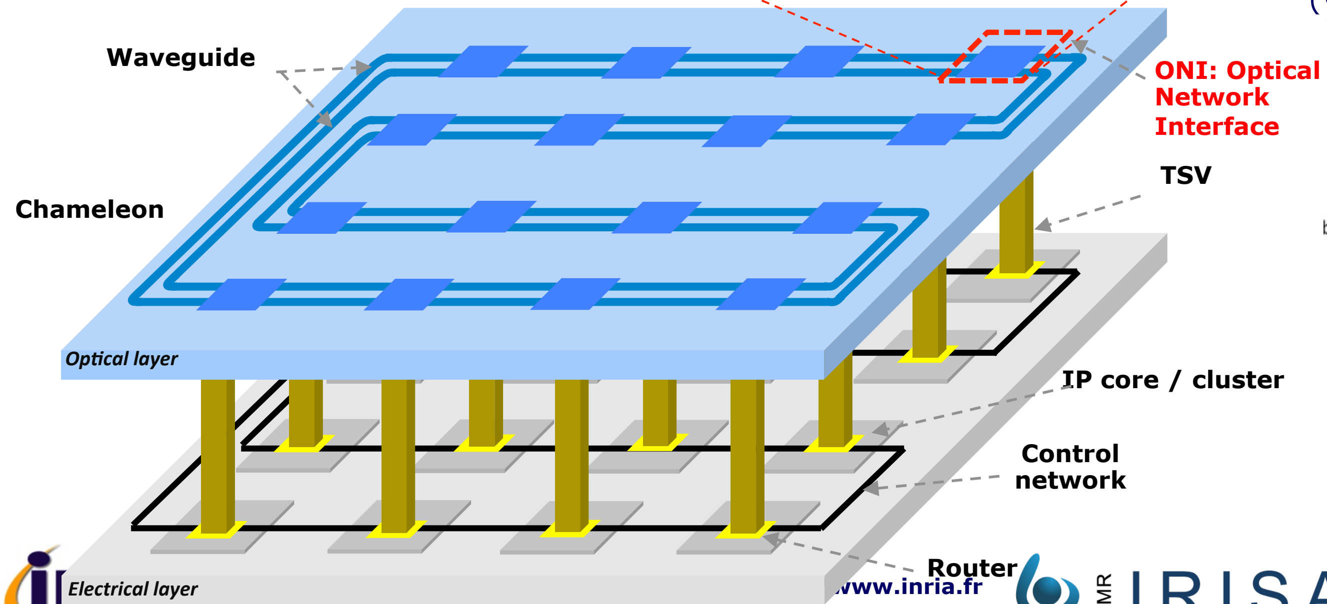


Z. Li et al. 2008

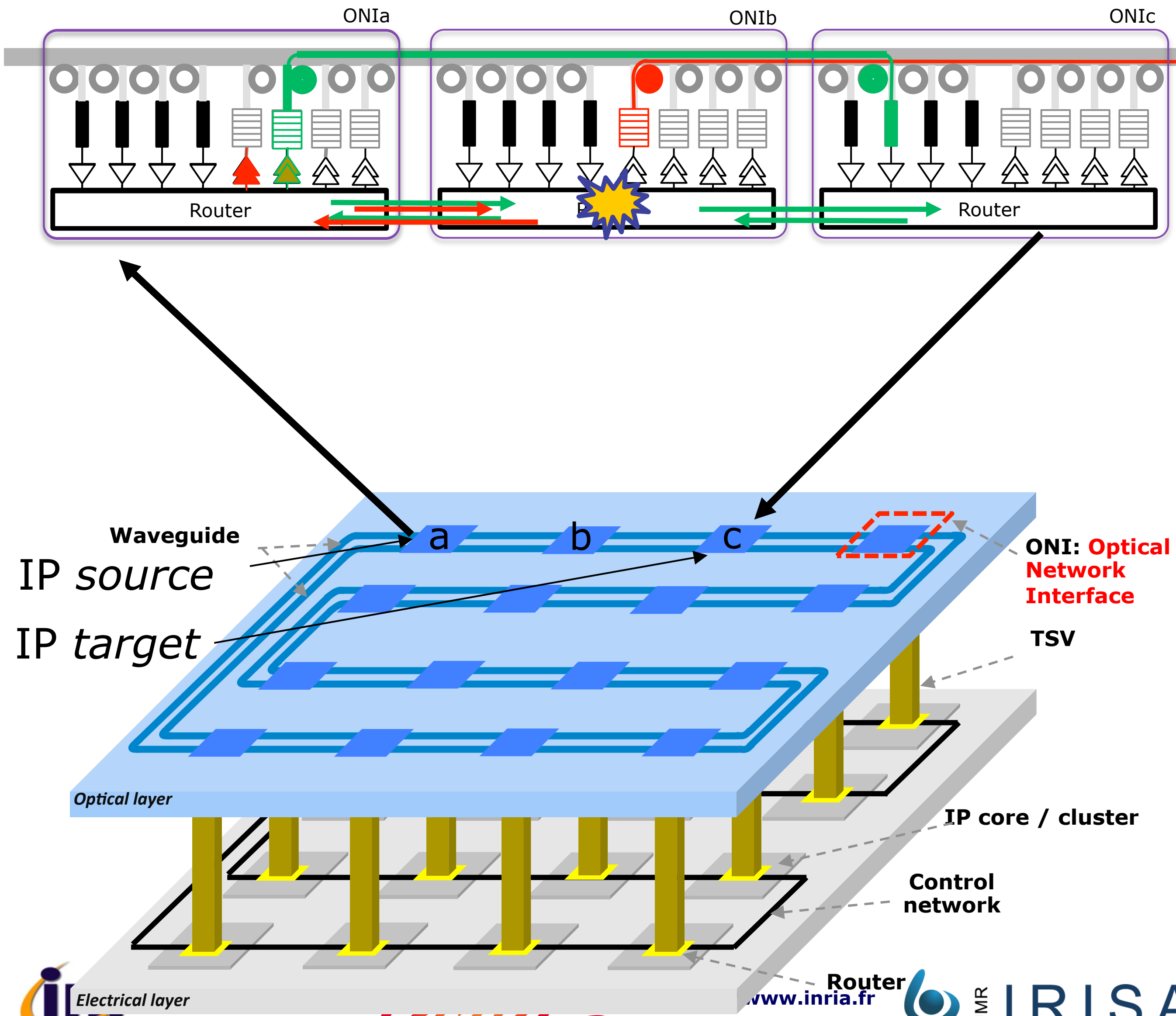
CMOS-compatible VCSEL
(Vertical-Cavity Surface-Emitting Lasers)

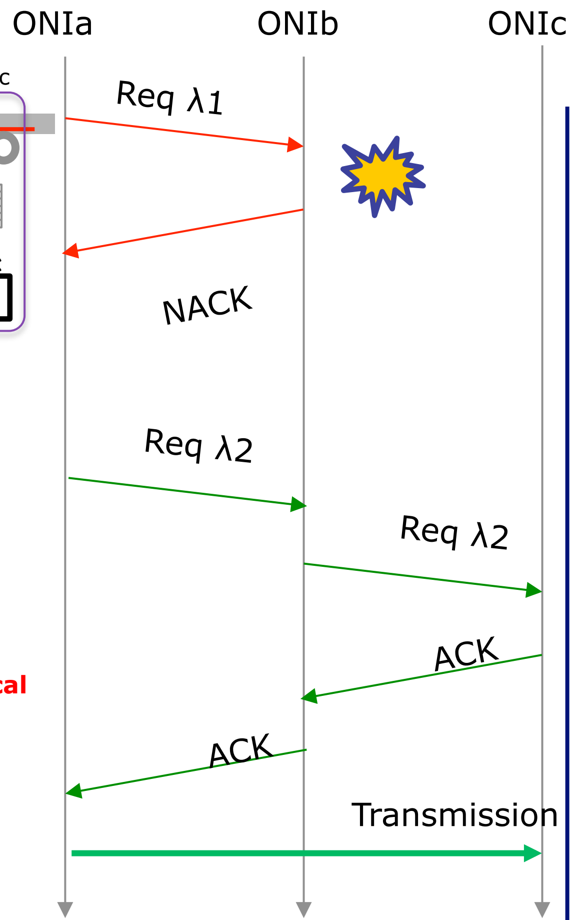


Source:
- C. Sciancalepore, et al. IEEE Photonics journal. 2012.
- Markus-Christian Amann and Werner Hofmann. IEEE journal of Selected Topics in Quantum Electronics , 2009.



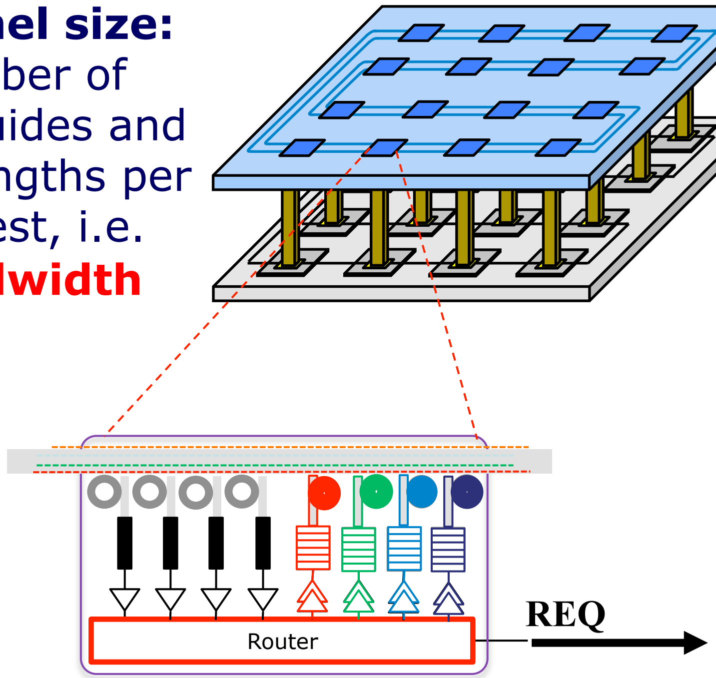
Communication schemes



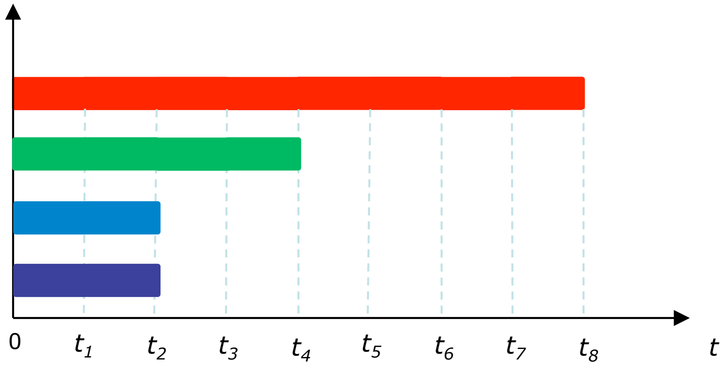


Channel size design tradeoff

Channel size:
number of waveguides and wavelengths per request, i.e.
bandwidth



data transfer time (optical domain)
versus
request latency (electrical domain)



Best design option?

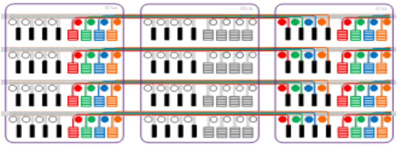
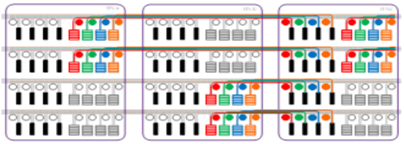
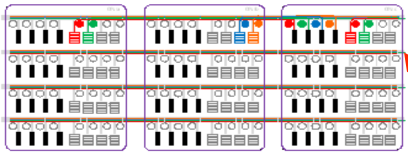
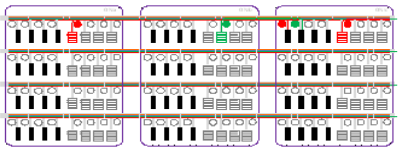
Simulation parameters

- **Models based on Gem5**
  - Quasi-cycle accurate simulator
  - Integration of C++ models of optical components
  - Based on Garnet NoC

- **Simulation characteristics**
  - Ring-based optical interconnection
  - 8-tiles (ARM, 4-KB L1 cache) 32 bits channel width
  - 2 architectures :
    - 4 waveguides, 16 wavelengths for each waveguide
    - 16 waveguides, 16 wavelengths for each waveguide
  - Modulation speed: 10Gb/s
  - Real application traffic (SPLASH-2)

Controller Synthesis Results

- 28nm FSDOI technology (Synopys Design Vision environment)

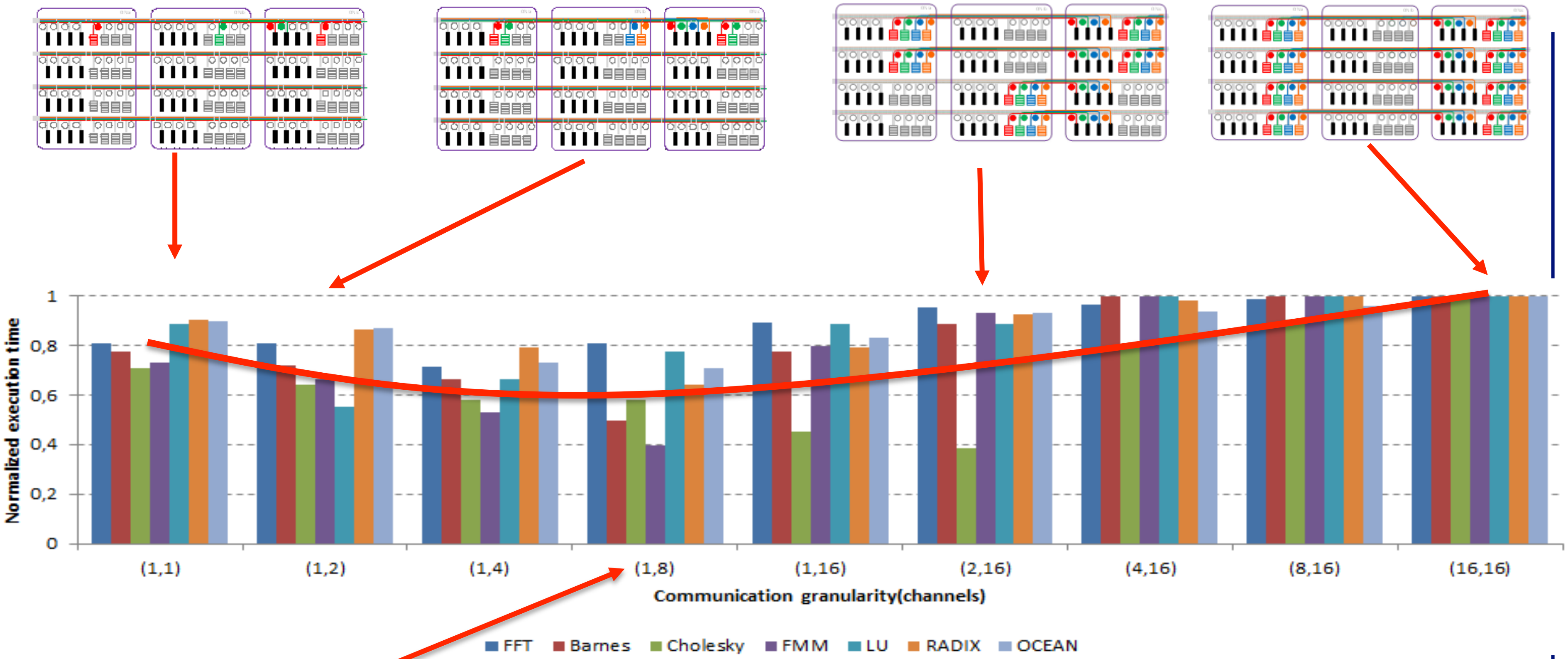





Network size	4 waveguides		16 waveguides	
Channel size (wg,wl)	Area (um^2)	Power (mW)	Area (um^2)	Power (mW)
(16,16)	NA	NA	6292	2.09
(8,16)	NA	NA	6629	2.21
(4,16)	6292	2.09	7304	2.45
(2,16)	6629	2.21	8781	2.95
(1,16)	7304	2.45	13538	4.45
(1,8)	8781	2.95	17022	5.06
(1,4)	13538	4.45	21385	5.33
(1,2)	17022	5.06	30110	5.86
(1,1)	21385	5.33	47560	6.92

Simple controllers

More complex controllers

Results: SPLASH-2 benchmark



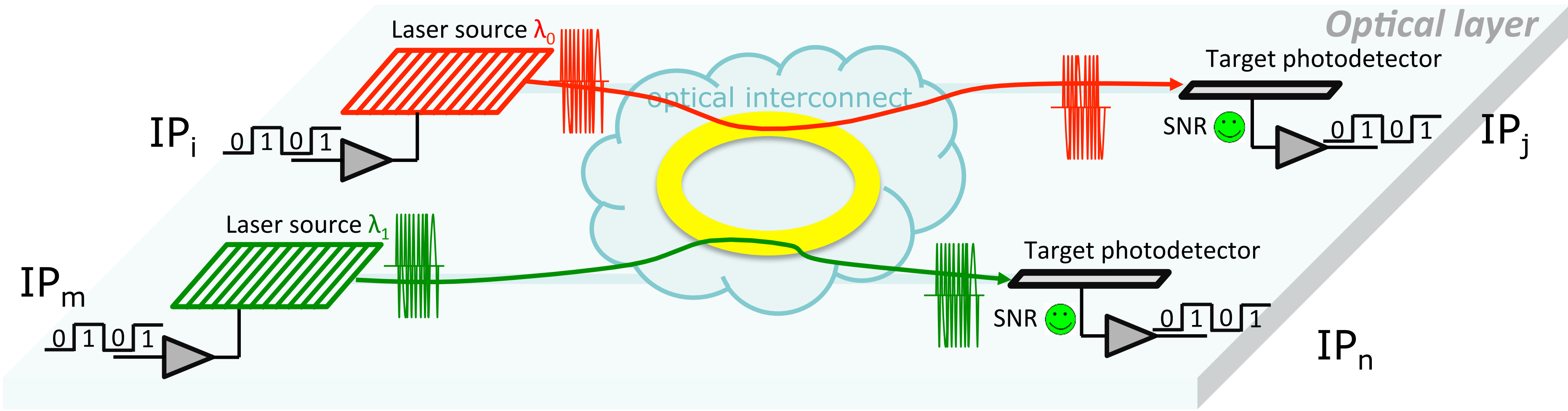
Best channel size: 1 waveguide, 8 wavelengths

Sepuulveda15] Communication Aware Design Method for Optical Network-on-Chip
J.Sepúlveda, S.Le Beux, J.Luo, C.Killian, D.Chillet, H.Li, I.O'Connor, O.Sentieys

Outline

- Context and problematic
- DSE of Waveguides and wavelengths allocation
- **DSE of laser power management**
- Conclusion

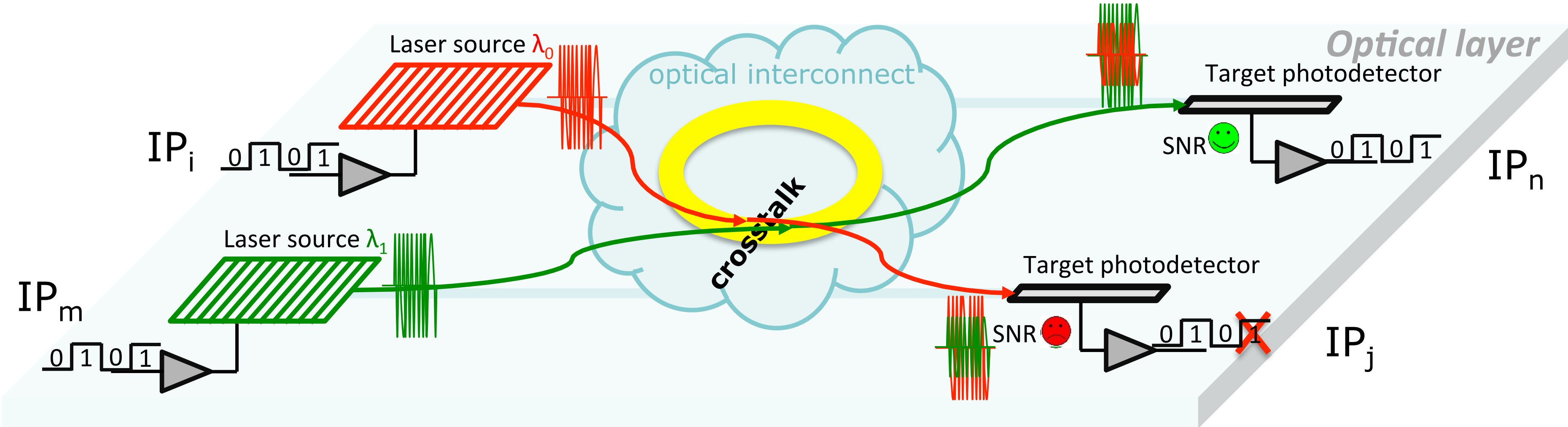
Impact of the waveguide sharing



- **Communication between 2 pairs of Ips**
  - One wavelength for each communication
  - **No conflict between communications**

- **Laser power at nominal value**

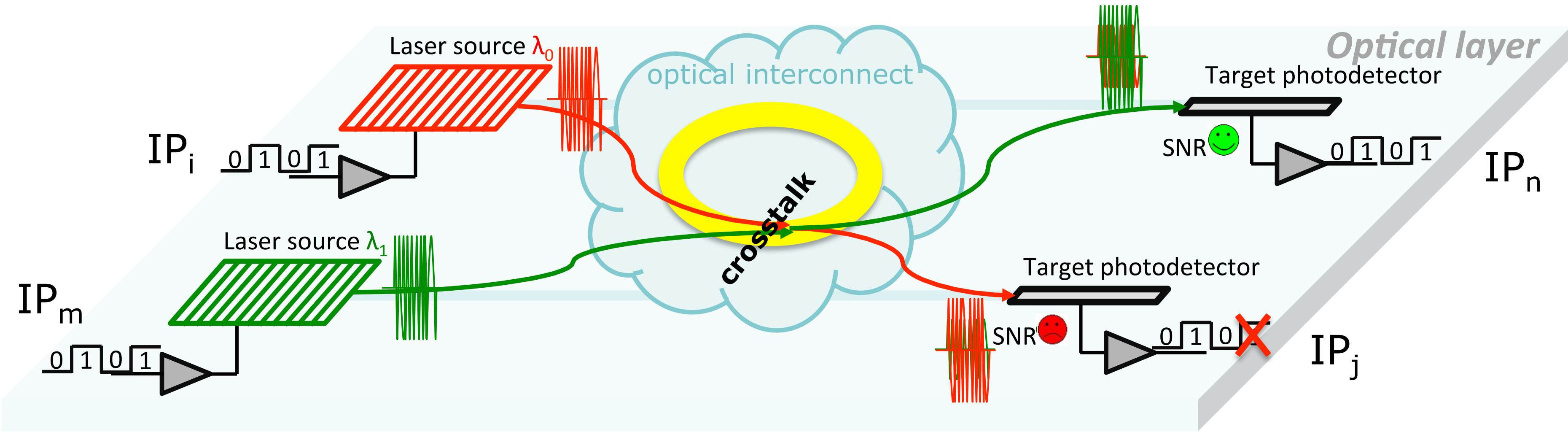
Impact of the waveguide sharing



- **Communication between 2 pairs of Ips**
  - One wavelength for each communication
  - **Temporal and spatial conflicts in the waveguide**

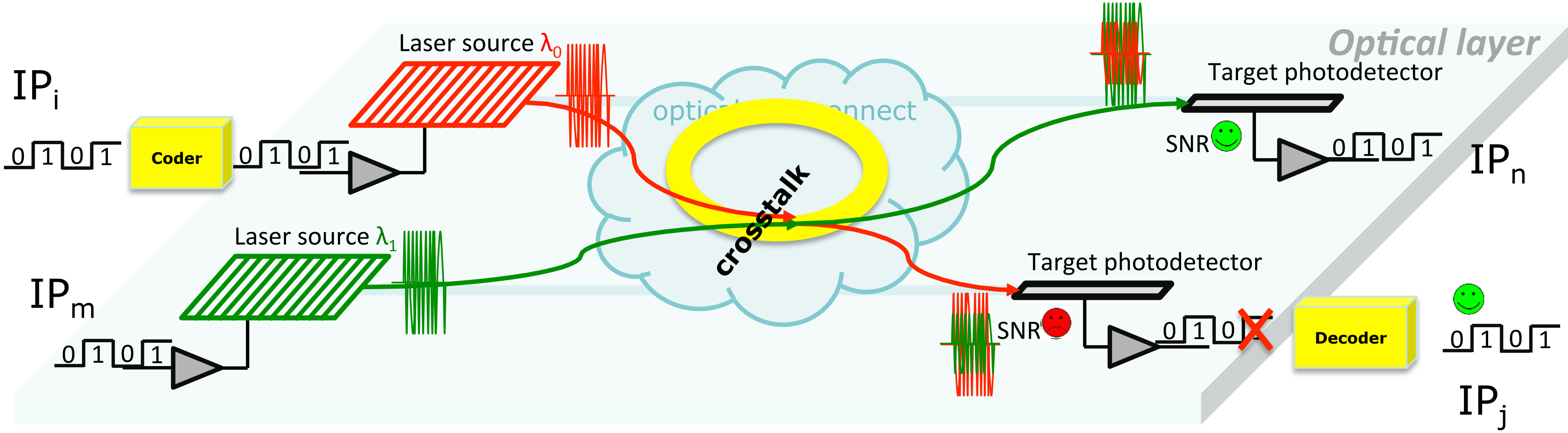
- **Laser power at nominal value**
  - SNR ↘ BER ↗

Impact of the waveguide sharing



- How can we manage SNR and BER ?
- Laser power can be ↗
  - SNR ↗ BER ↘

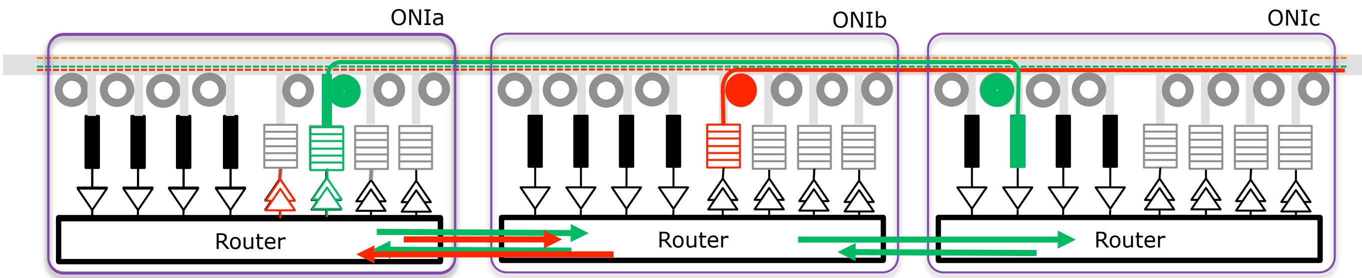
Impact of the waveguide sharing



- How can we manage SNR and BER ?
- Laser power can be ↗
  - SNR ↗ BER ↘
- Or ECC can be included in the communication channel
  - SNR = BER ↘ but BW ↘

Impact of the waveguide sharing

- **Strategy**
  - **How to find a good tradeoff between**
    - **management of laser power**
    - **introduction of codec in the channel**
  - **Could be supported by the allocation protocol**
    - **req. and ack. messages can help to estimate the loss in the optical channel**



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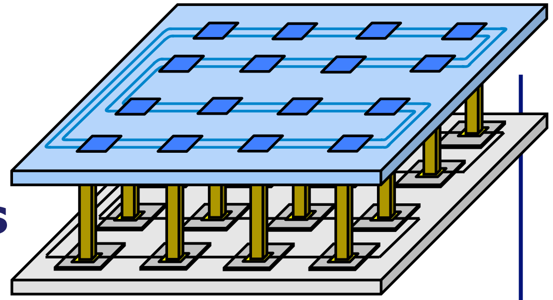
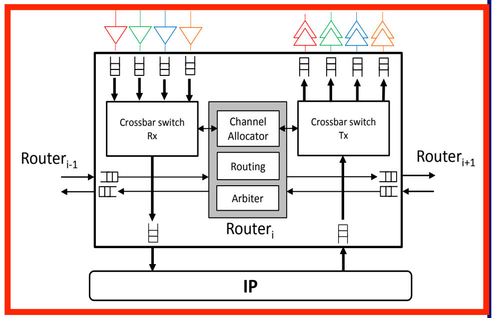
Conclusion and future works

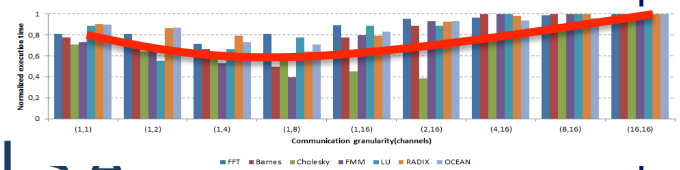
- **Optical NoC Interface design**
  - **critical issue in silicon photonics interconnects → need DSE at different levels**



    - **low level DSE/management**
      - **laser power and ECC**
    - **high level DSE/management**
      - **channel allocation / allocation protocol**



- **Future works**
  - **tradeoff between Electric vs Optic energy performances**
    - **on-line strategy for channel allocation**
  - ***thermal aware design method***



ComminLabs — 3D Optical Many Cores — DATE 16, 14–18 MARCH, 2016

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Thank you !

Questions ?