A Tool for Synthesizing Power-Efficient and Custom-Tailored Wavelength-Routed Optical Rings

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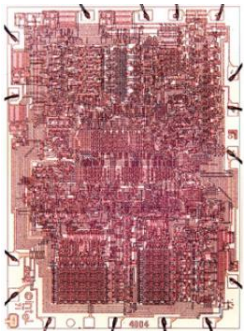
DA SEICENTO ANNI GUARDIAMO AVANTI.

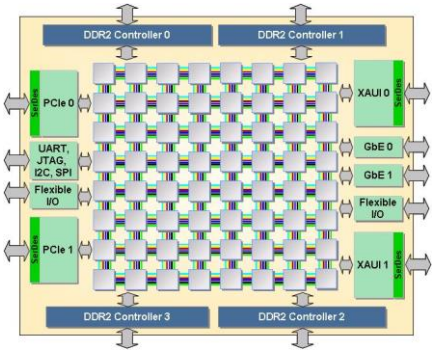
Networks-on-Chip Motivation

1971



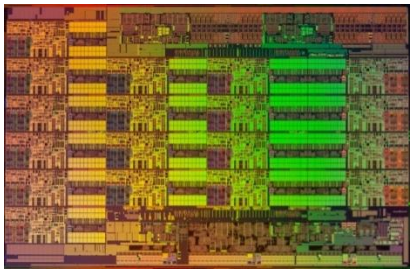
Intel 4004
1 core
no cache

2008



TILEPro64
64 cores
4MB cache

2015



Intel Xeon E5-2699
18 cores
45MB cache

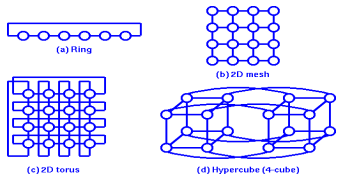
2020
Prediction

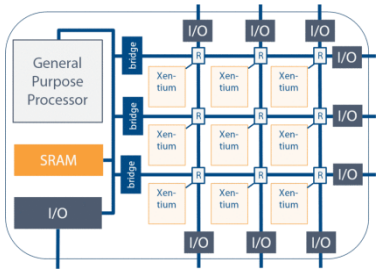
Hundreds of cores
380MB cache

We have to connect all the cores and chip components: NETWORK ON CHIP

Optical on-Chip Communications

- **Electronic NoCs**



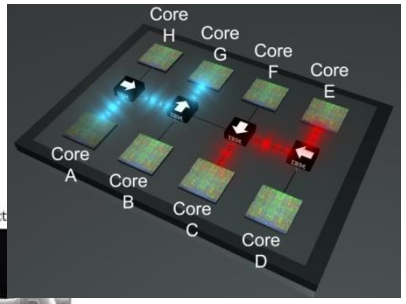


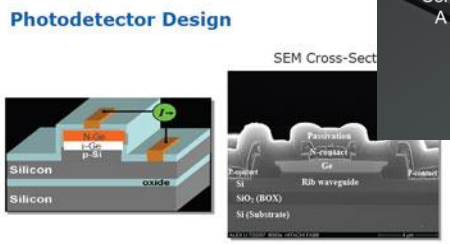
- ✗ High energy dissipation
- ✗ Latency overhead
- ✗ Throughput-limited
- ✗ Going off-chip is expensive

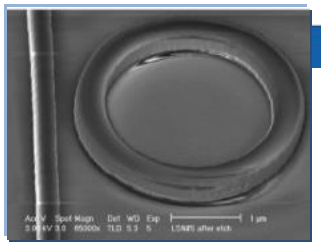
- **Optical NoCs**

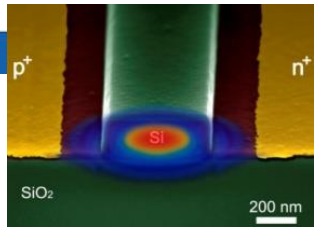
Photonic elements can be integrated on a silicon chip

- ✓ High bandwidth
- ✓ Low latency
- ✓ Low energy



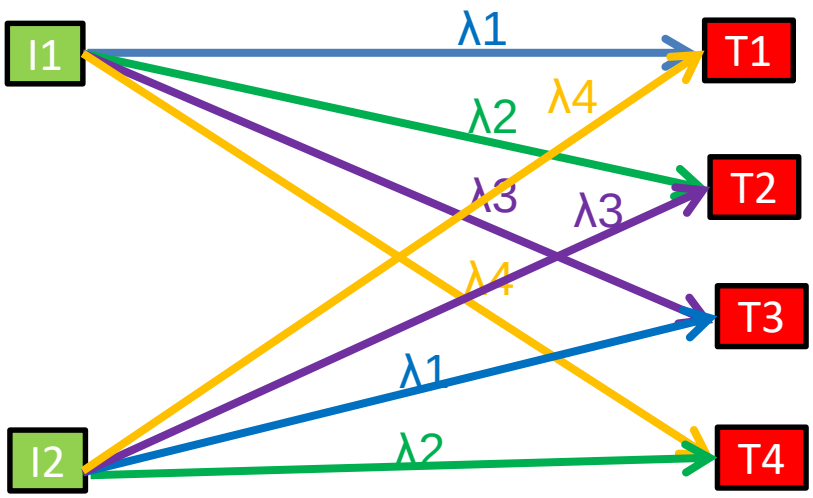






Wavelength-Routed Optical NoCs

Virtual view of wavelength-selective routing



Suitable for latency critical applications

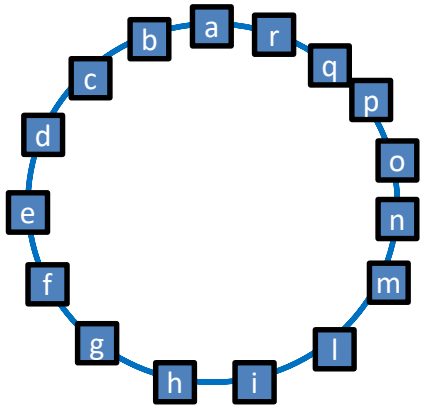
CHALLENGE: Difficult to scale to a large number of nodes

Benefits

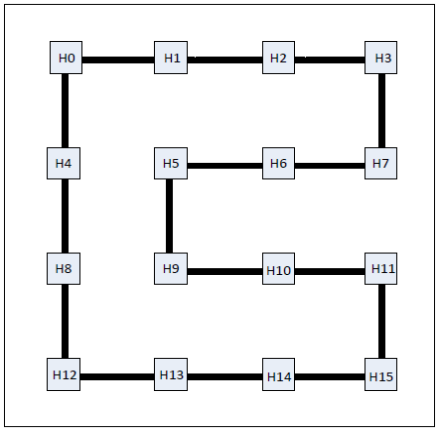
- **No routing or arbitration**
- **Contention-free full connectivity without path setup/teardown overhead**

Optical Ring

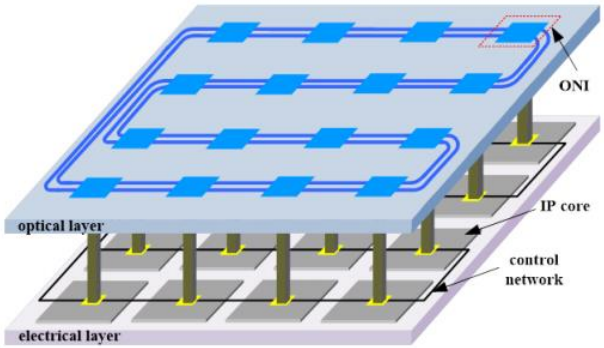
Logical Scheme



Physical Layout



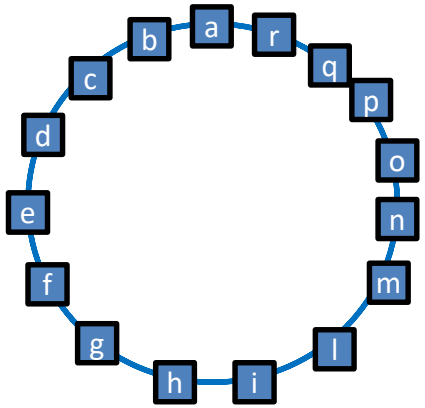
3D Stacking



We model the ring considering the place&route constraints

Optical Ring

Logical Scheme



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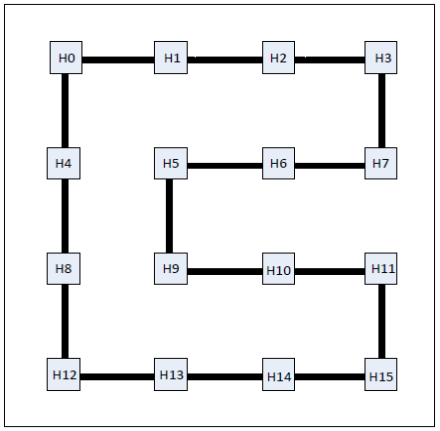

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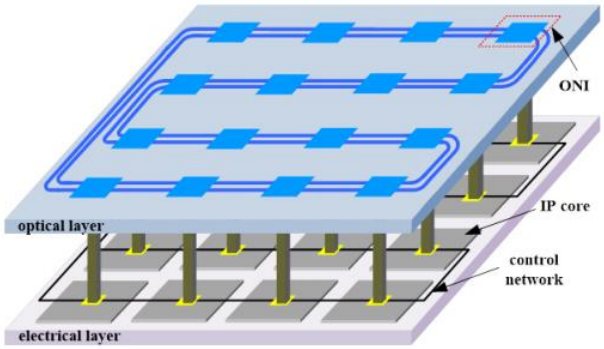

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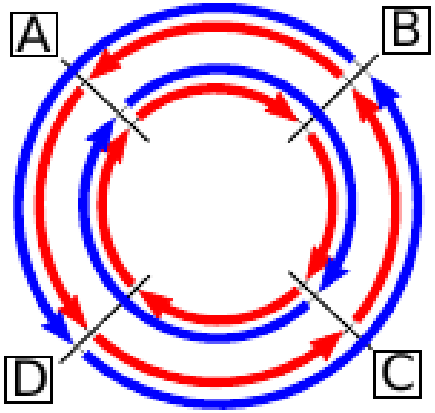
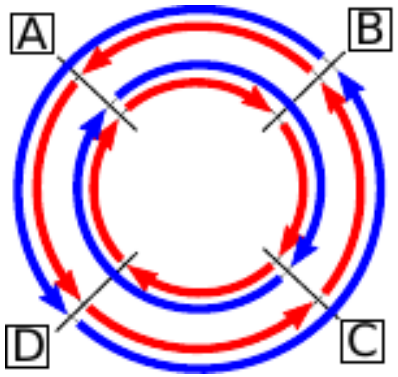


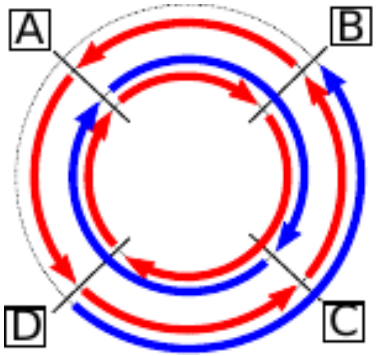
	A	B	C	D
A	-	λ_1	λ_2	λ_1
B	λ_1	-	λ_1	λ_2
C	λ_2	λ_1	-	λ_1
D	λ_1	λ_2	λ_1	-

The same wavelength can be reused on the same waveguide to establish multiple and non-overlapping communications

Optical Ring Design Motivation



	A	B	C	D
A	-	λ_1	λ_2	λ_1
B	λ_1	-	λ_1	λ_2
C	λ_2	λ_1	-	λ_1
D	λ_1	λ_2	λ_1	-



	A	B	C	D
A	-	λ_1	λ_2	λ_1
B	λ_1	-	X	λ_1
C	λ_2	λ_1	-	X
D	λ_1	λ_2	λ_1	-

Goal: Implement all communications minimizing the number of waveguides & wavelengths and power consumption

Restriction: The same wavelength cannot be used in the same section of a waveguide twice

[LeBeux2011] The only proposal to automatically generate optical rings

Outline

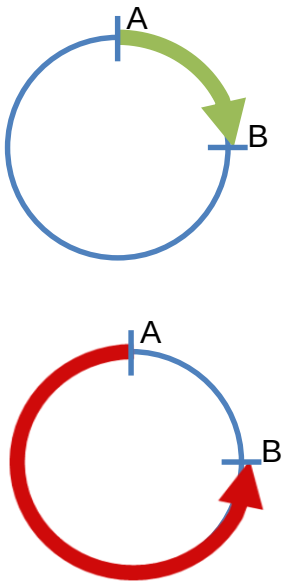
1. **Generating the Ring**
2. Calculating the Power
3. Evaluation
4. Conclusions

Generating the Ring

INPUT: #waveguides, max #wavelengths, communications
OUTPUT: waveguide matrix, wavelength matrix

For every communication that has to be implemented:

1. Try to reuse a wavelength to set the communication on the short path
2. Try to set the communication on the short path with a new wavelength
3. Try to reuse a wavelength to set the communication on the long path
4. If everything fails → Cannot generate ring



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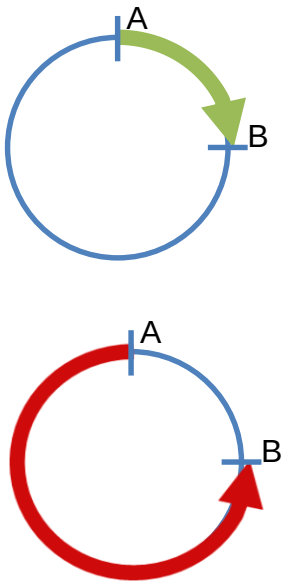
Give priority to short paths



Generating the Ring

INPUT: #waveguides, max # tions
OUTPUT: waveguide matrix

ORDER TO SET THE COMMUNICATIONS:
Long communications first works better

For every communication th

1. Try to reuse a wavelength to set the communication on the short path
2. Try to set the communication on the short path with a new wavelength
3. Try to reuse a wavelength to set he long path
4. If everything fails → Cannot generate ring

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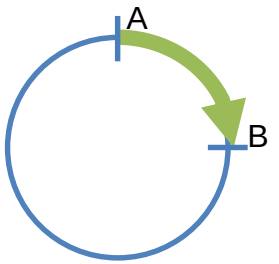

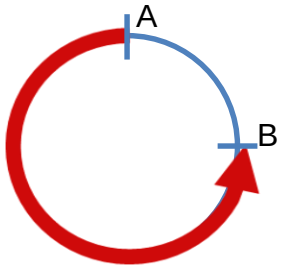

Outline

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2. **Calculating the Power**
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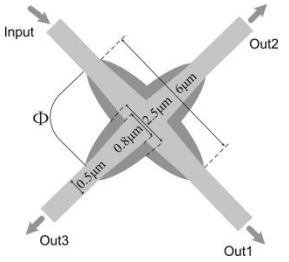
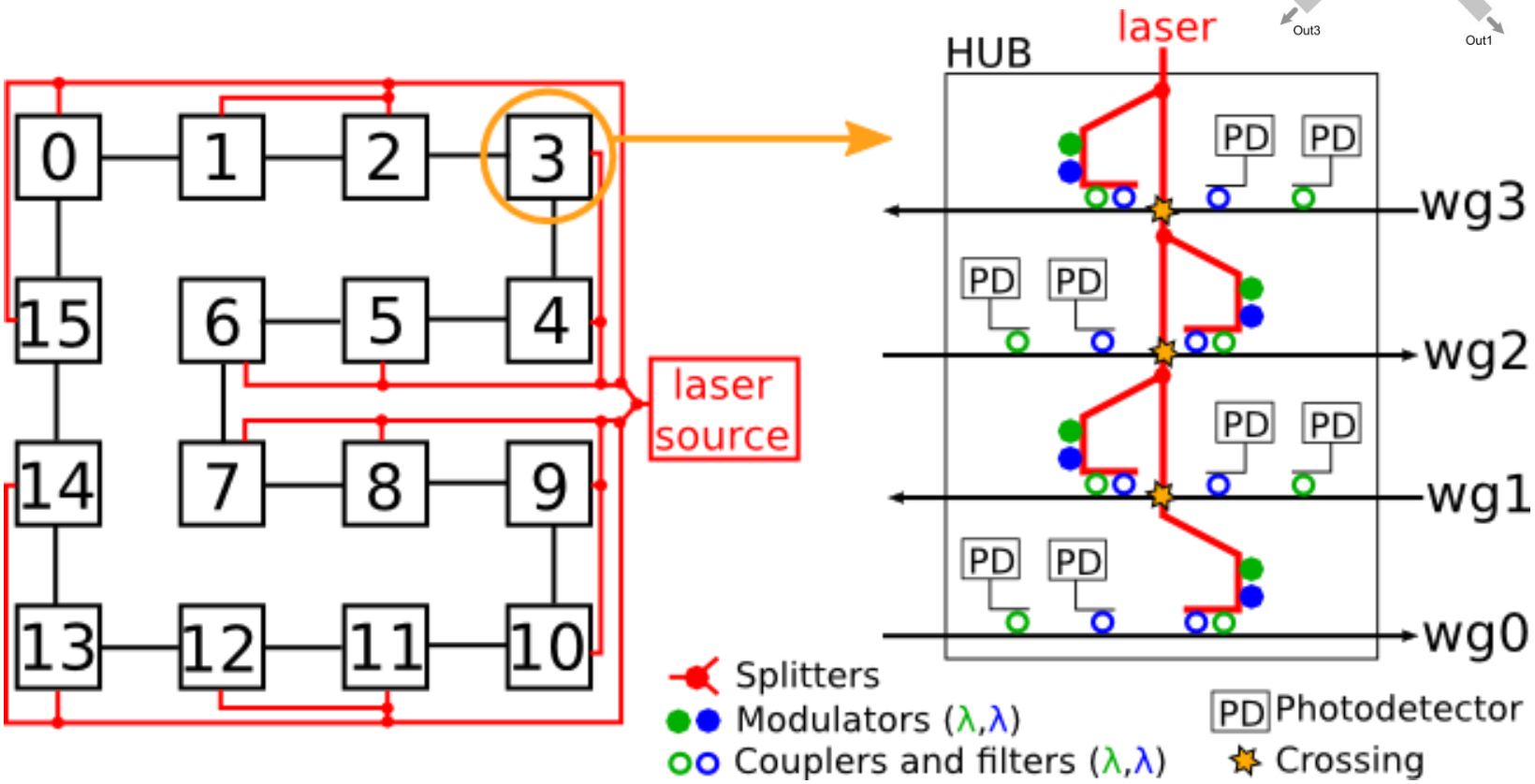
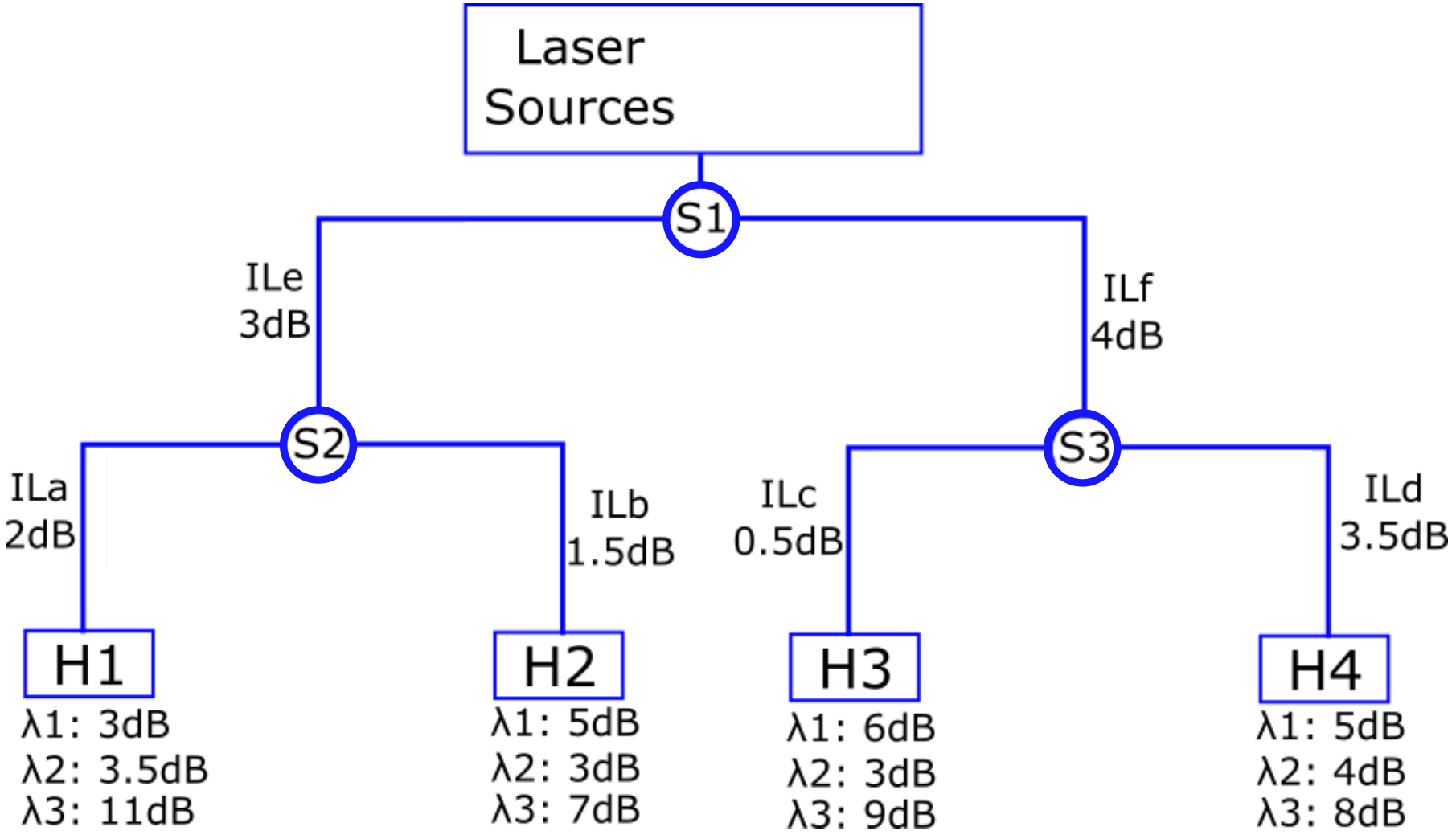
Calculating the Power

- Include laser distribution network
- Consider crossings normally overlooked





Calculating the Power



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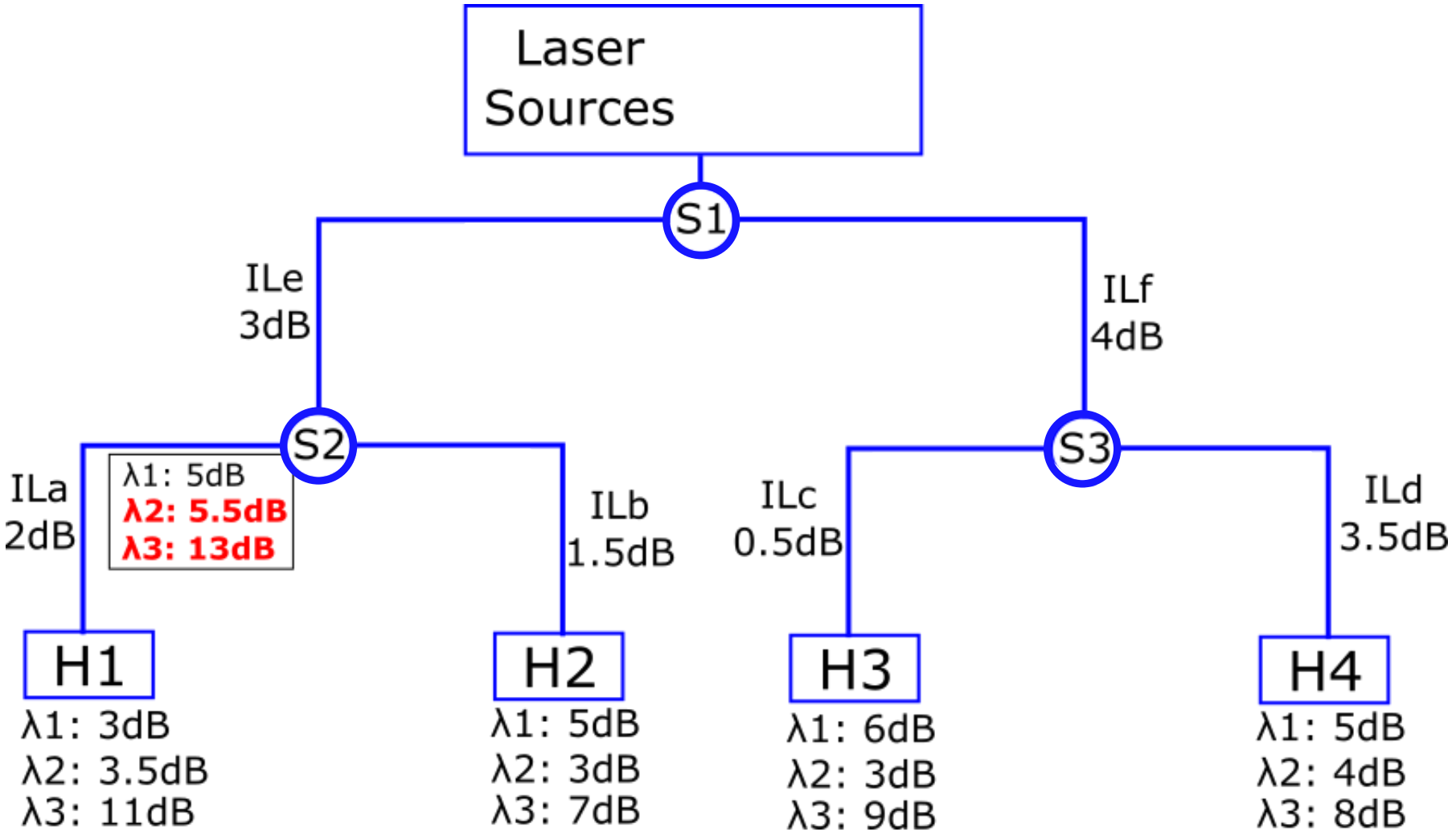
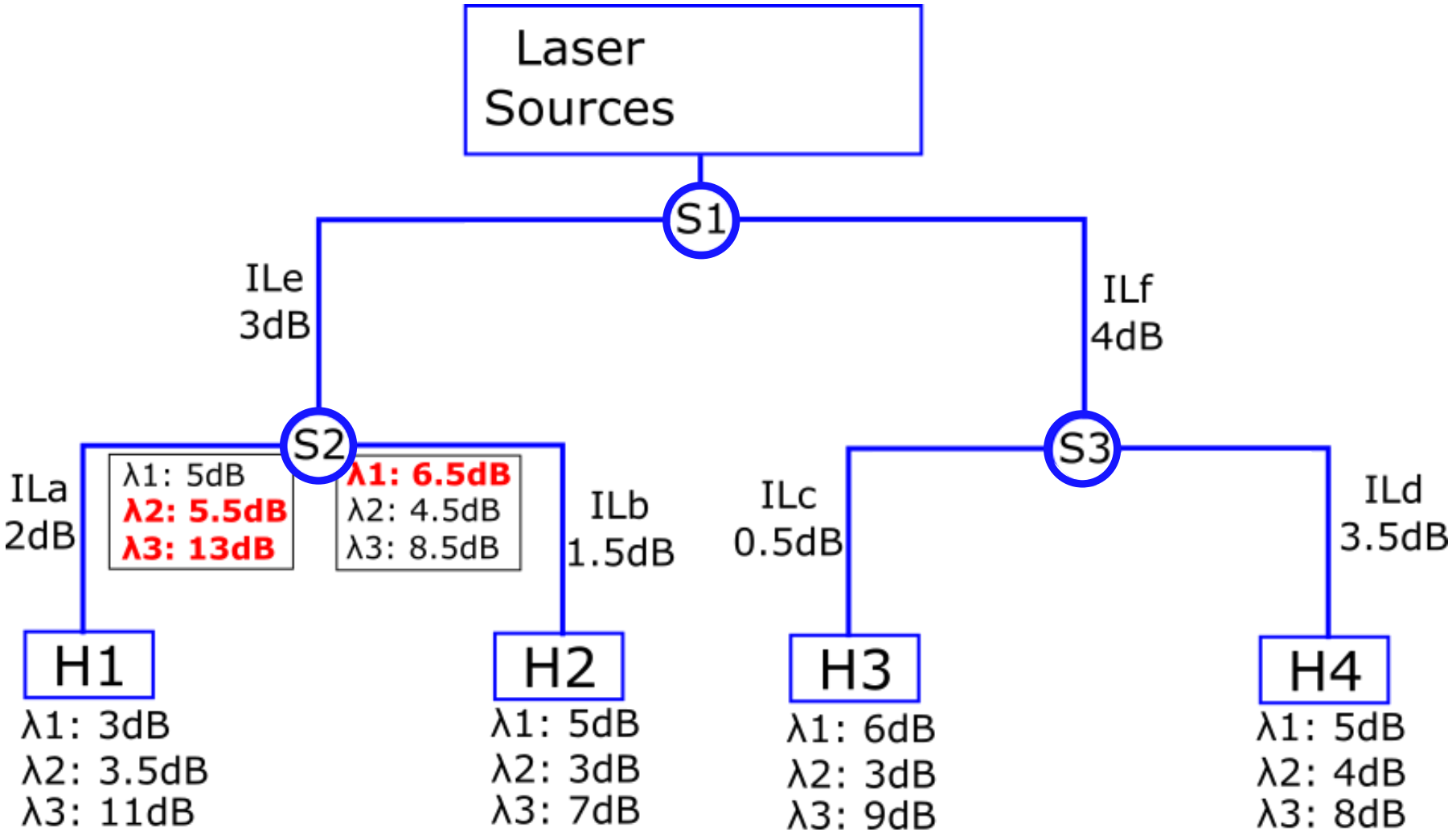
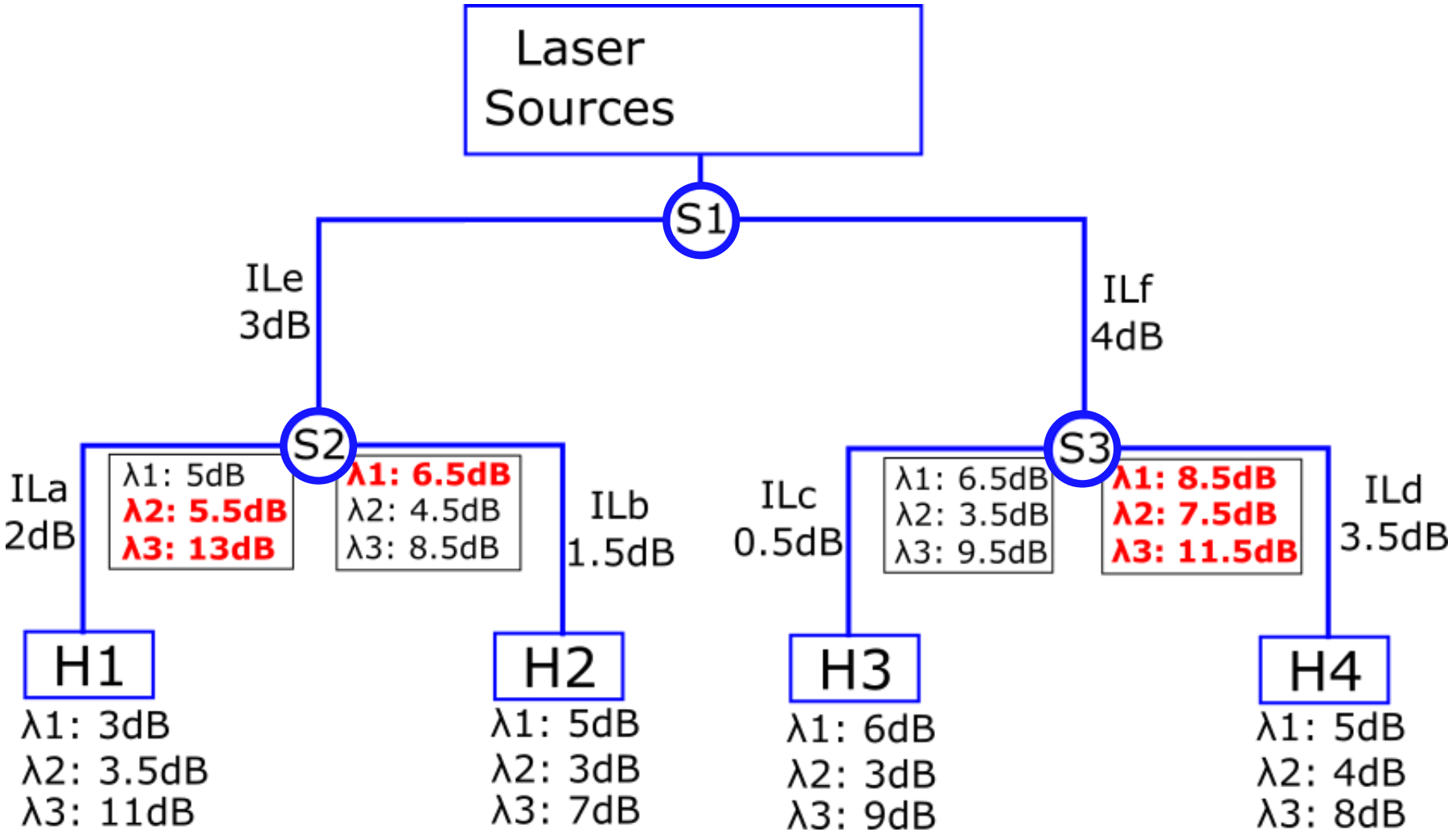


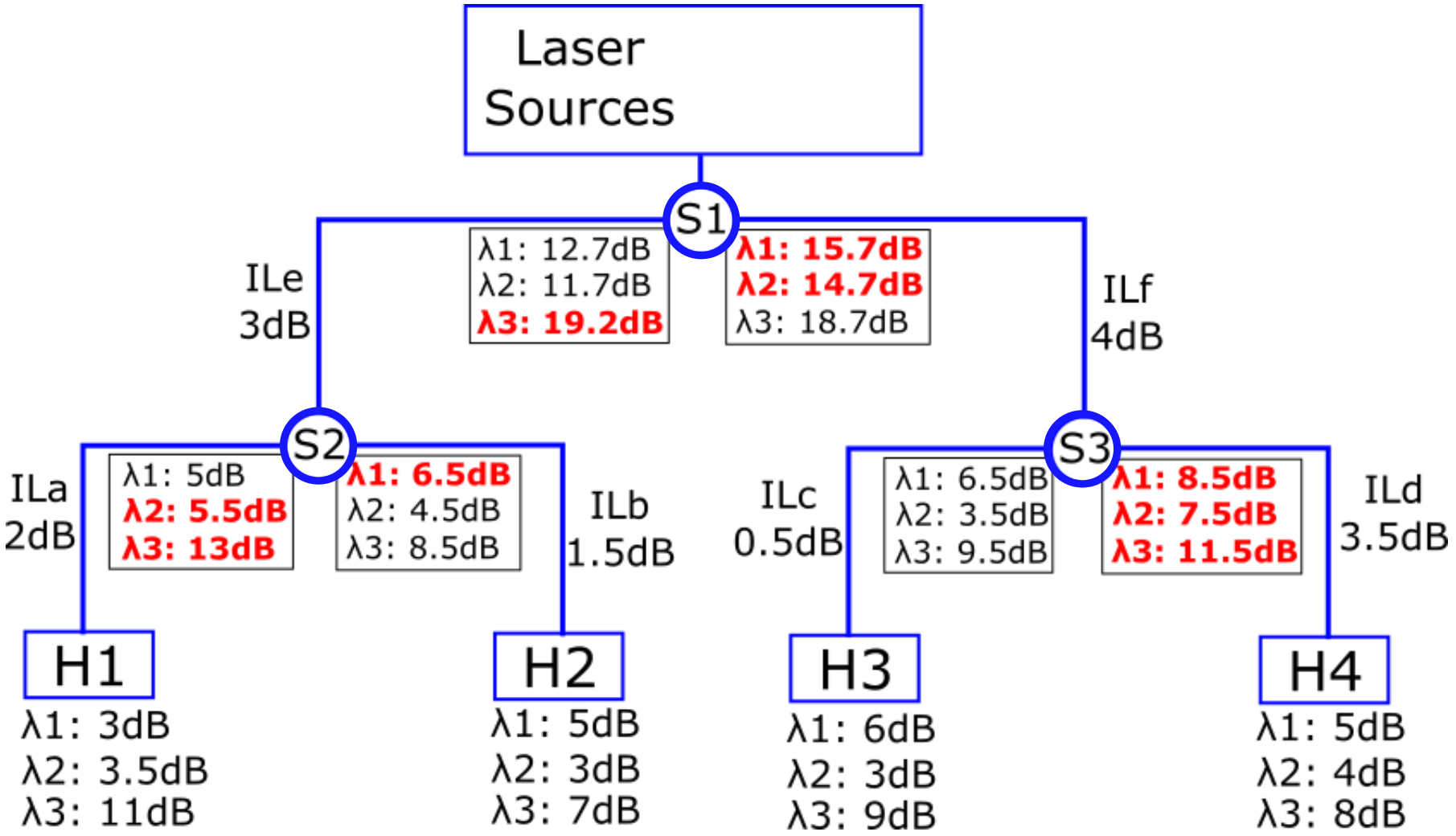
Calculating the Power



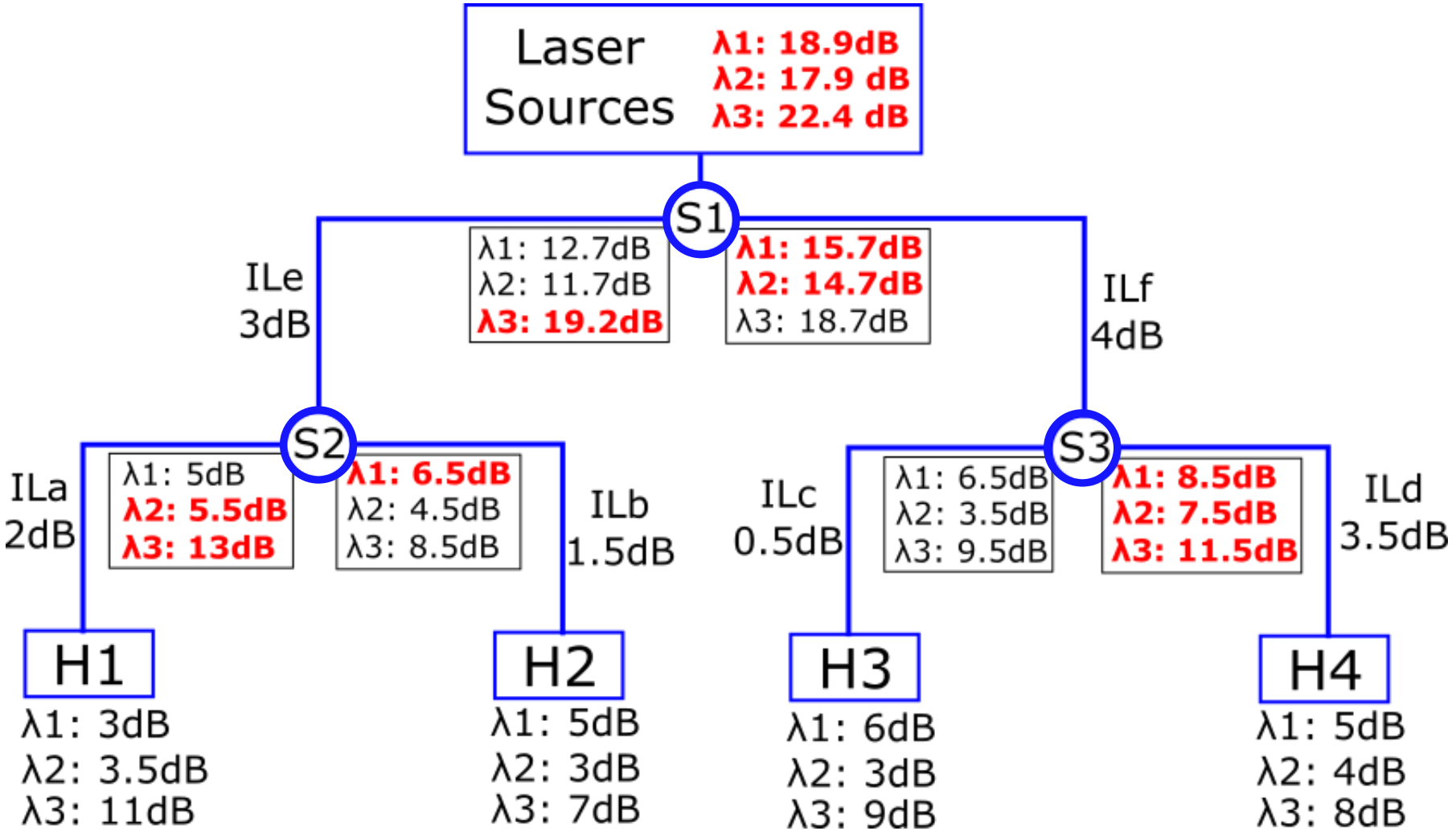
Calculating the Power



Calculating the Power



Calculating the Power



Outline

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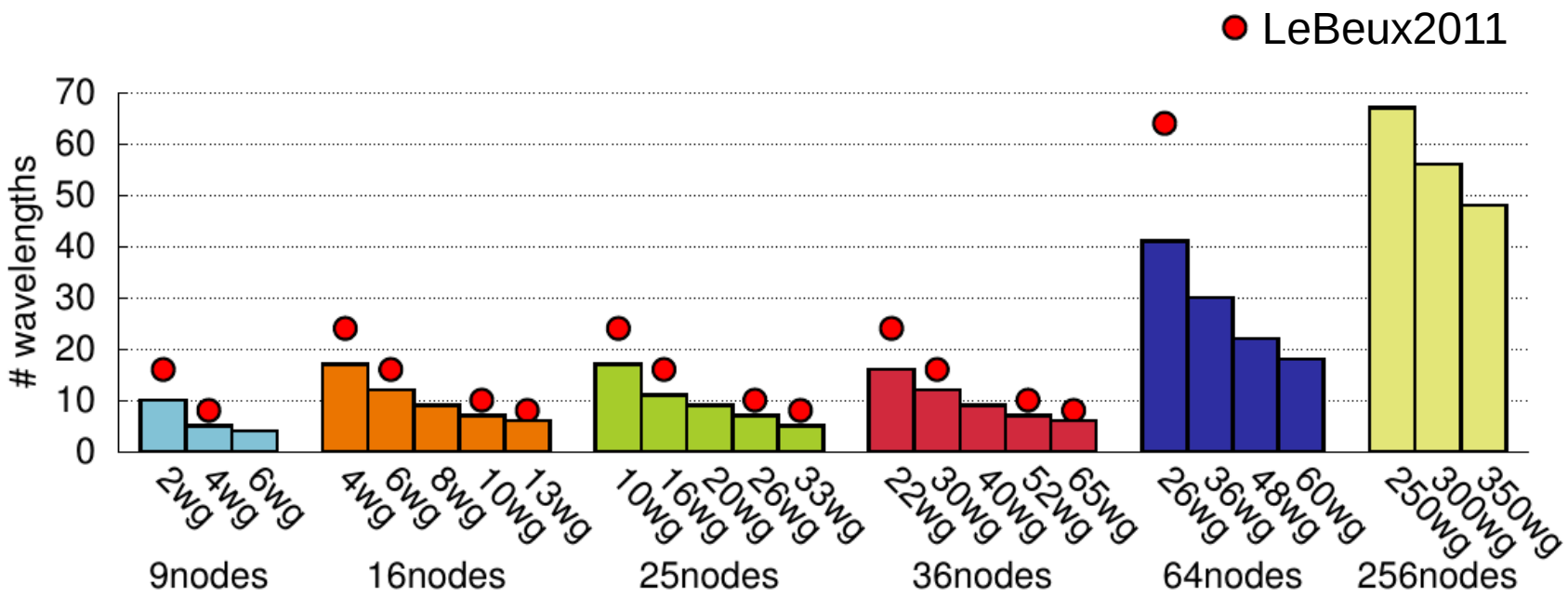
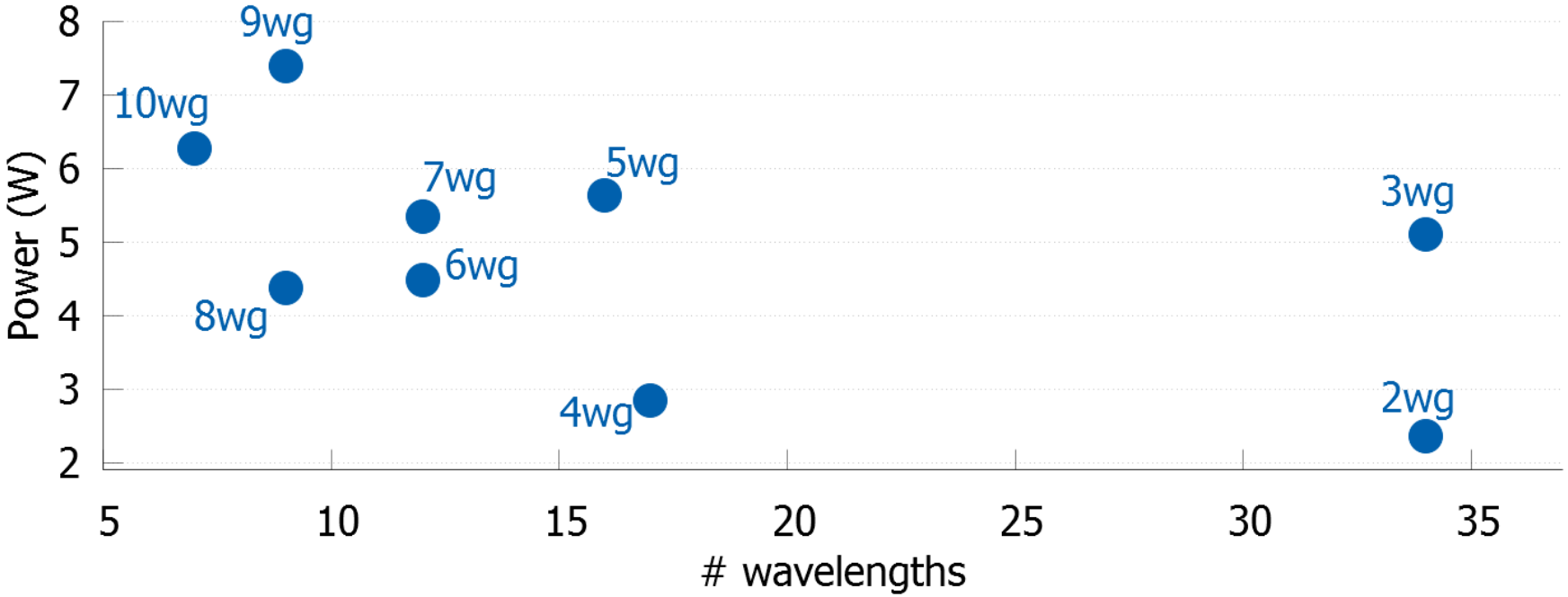
2. Calculating the Power
3. **Evaluation**
4. Conclusions

Number of Waveguides & Wavelengths



We can build rings with
fewer waveguides and/or wavelengths

Power Consumption – 16 nodes



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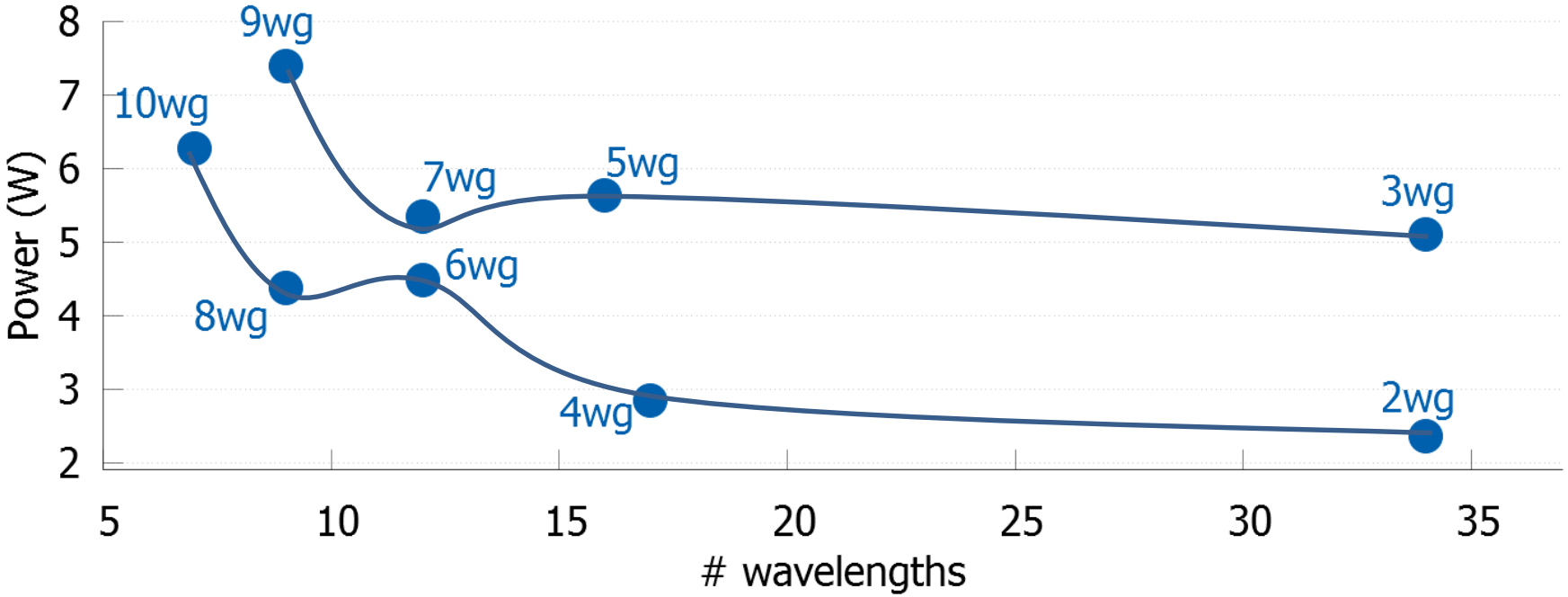
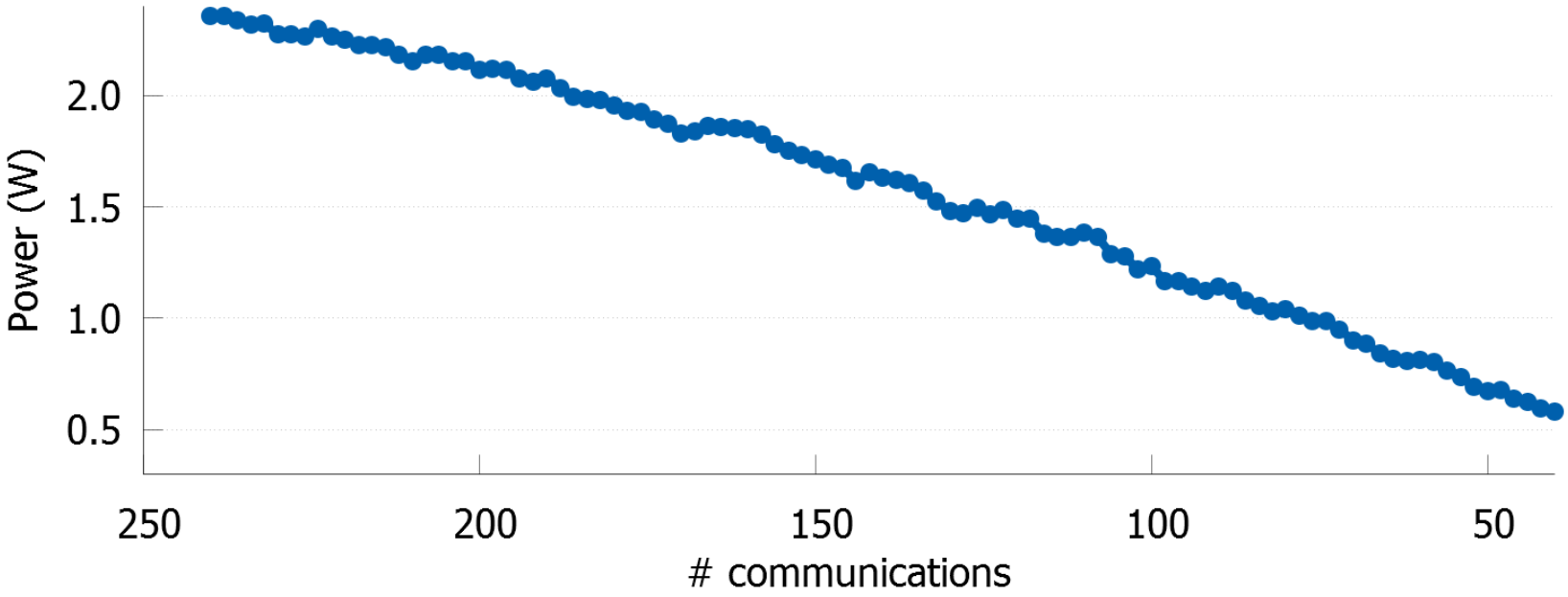


- Results are better with an even number of waveguides
- Best configuration = only 2 waveguides

Customizable Ring Designs

Start with fully connected ring

and randomly remove connections



The algorithm generates optimized custom designs

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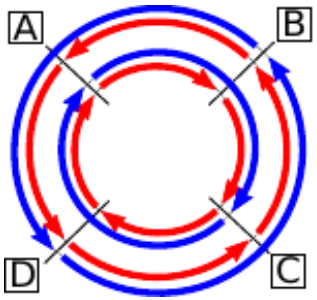
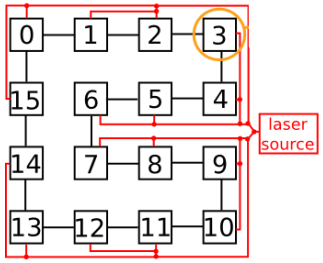
Conclusions

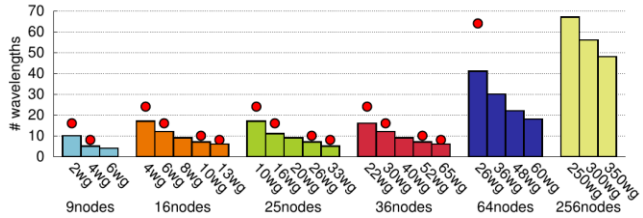
- Algorithm for automatic ring design and power calculation



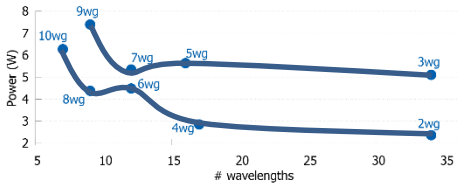
- We consider the power distribution network



- We obtain rings with fewer waveguides/wavelengths



- Adding wavelengths is more efficient than adding waveguides



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ASP-DAC 2017
16-19 January, Chiba/Tokyo (Japan)

Universidad Zaragoza
1542

Physical-Level Parameters

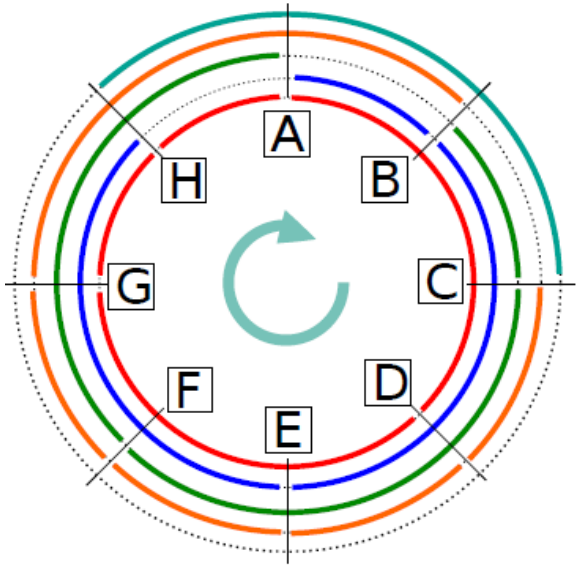
TABLE I: Physical level parameters.

Chip size	16x16 mm
Crossing loss	0.15 dB
Propagation loss	0.15 dB/mm
Bending loss	0.005 dB
Splitter loss	0.2 dB
Receiver sensitivity	-20 dBm

Modulator loss	1 dB
Coupler loss	1 dB
Filter drop loss	1 dB
Photodetector loss	1 dB
Coupler efficiency	90%
Laser efficiency	8%

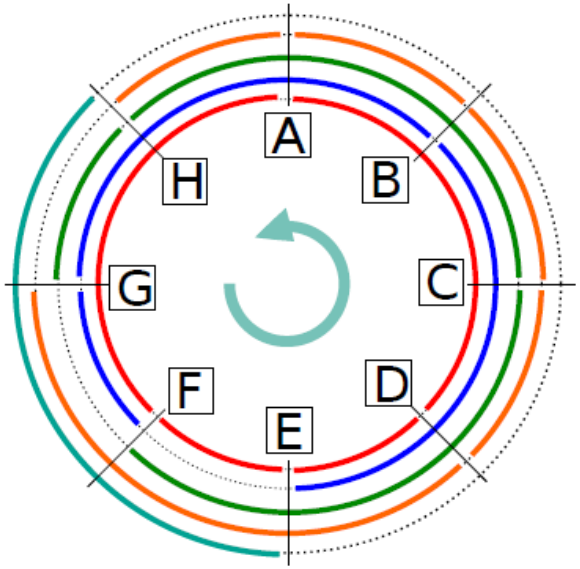
Detailed Example

Waveguide 0, clockwise



	A	B	C	D	E	F	G	H
A	-	1	-	0	-	-	-	-
B	-	-	2	-	1	-	-	-
C	-	-	-	3	-	2	-	-
D	-	-	-	-	3	-	0	-
E	-	-	-	-	-	3	-	1
F	2	-	-	-	-	-	3	-
G	-	3	-	-	-	-	-	0
H	0	-	4	-	-	-	-	-

Waveguide 1, counterclockwise



	A	B	C	D	E	F	G	H
A	-	-	-	-	-	0	-	3
B	3	-	-	-	-	-	1	-
C	-	3	-	-	-	-	-	2
D	0	-	3	-	-	-	-	-
E	-	1	-	0	-	-	-	-
F	-	-	2	-	0	-	-	-
G	-	-	-	3	-	1	-	-
H	-	-	-	-	4	-	2	-