IITD OPTICAL STACK : LAYERED ARCHITECTURE FOR PHOTONIC INTERCONNECTS

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Authors:

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Need For Interconnection

- Cache Coherence.
  - Send the broadcast signals.
  - Receive the responses from other caches.
- Barriers.
  - Send the barrier status to each other.
- Cores need to communicate with other caches.
  - Cache misses.
  - Cache line migrations

How to Connect these Cores on a Chip?

- **Point to point Interconnection**
  - Number of wires required = N*(N-1)/2.
  - Will be clumsy.

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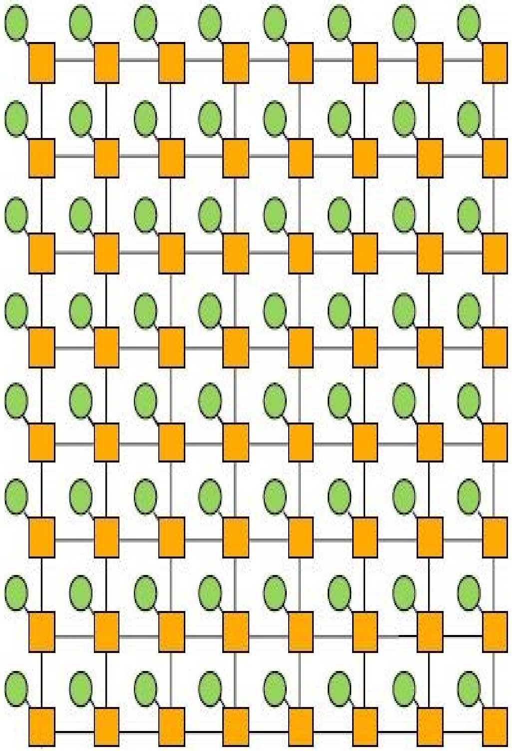
- **NOC**
  - Logical point to point links through a network.
  - Route packets in a network.
  - Will reduce the number of electrical links.



Why Optical?

- For electrical interconnects :

Interconnect Length

Delay

Power Consumption

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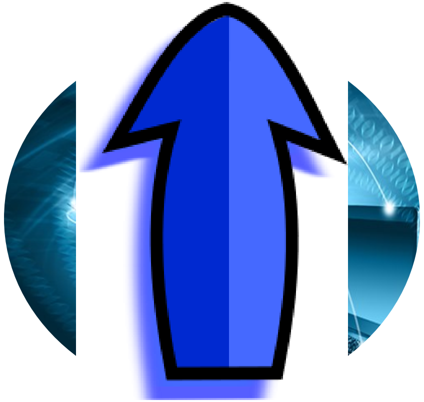

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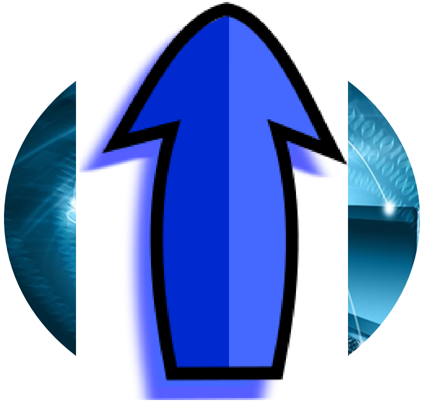

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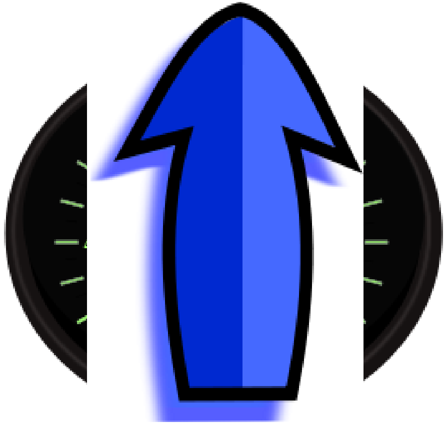

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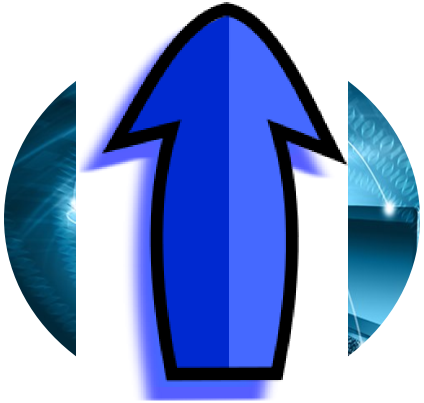

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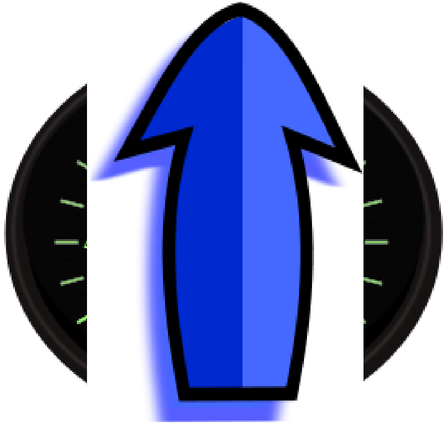

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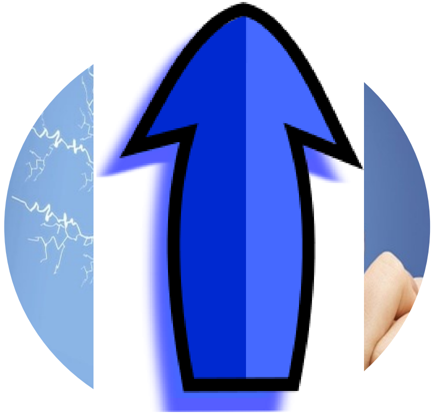

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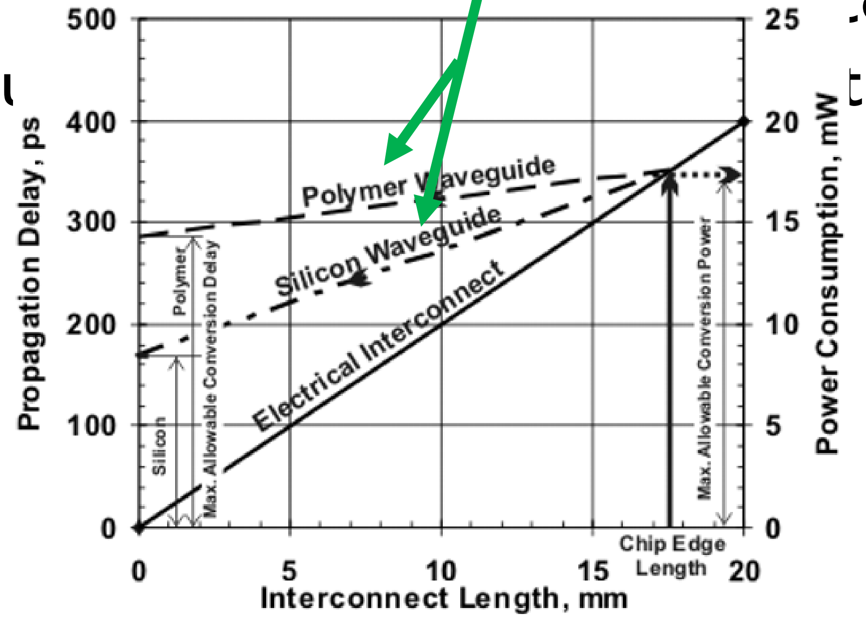

All figures reproduced from Haurylau et al. IEEE Journal of Quantum Elec.

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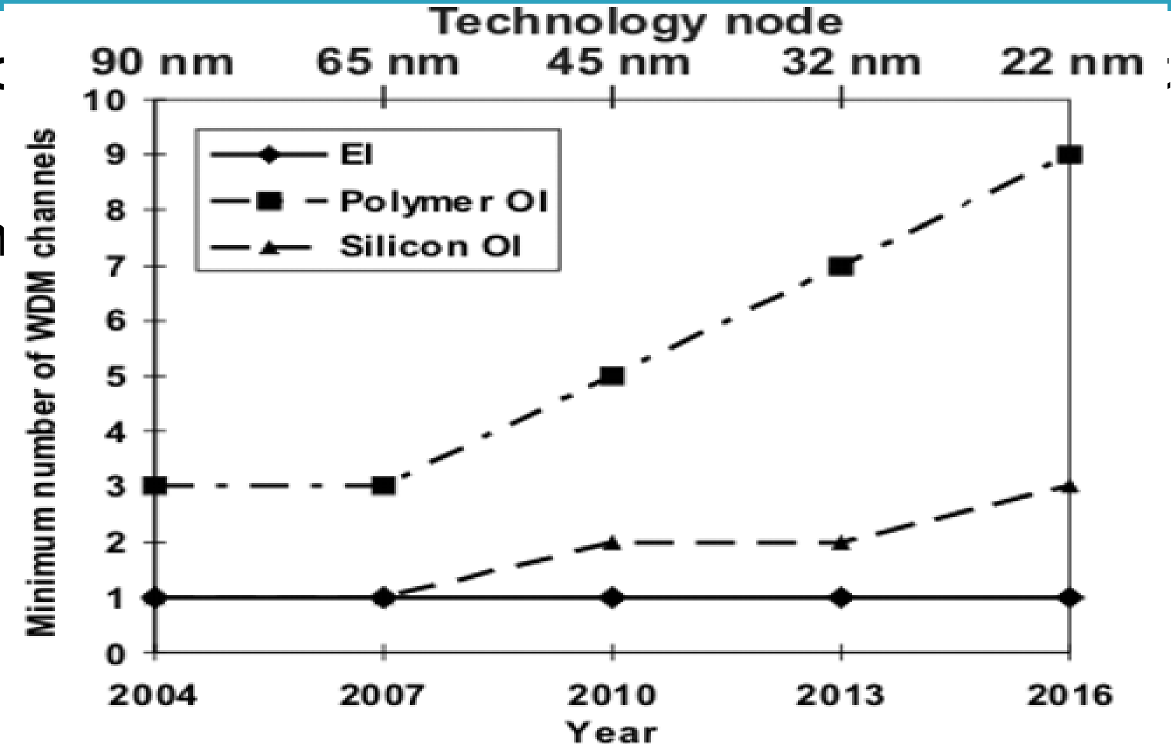

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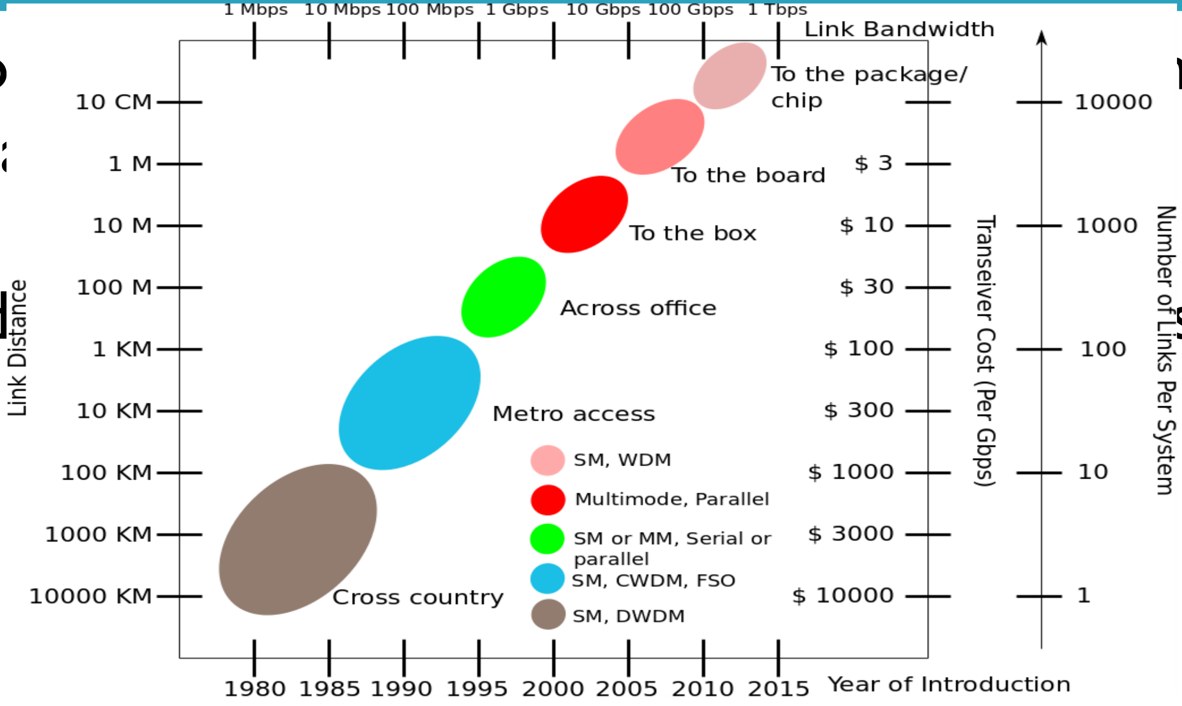

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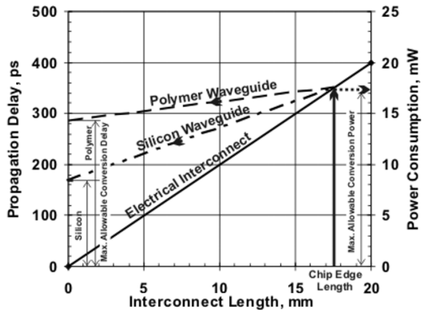

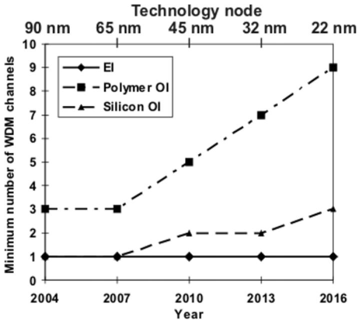

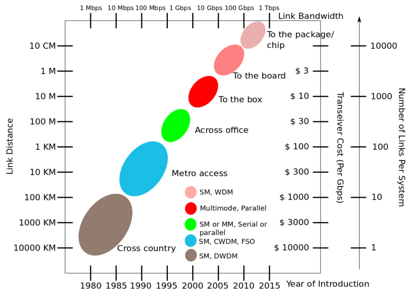

OUR OPTICAL STACK

Nanophotonics
domain

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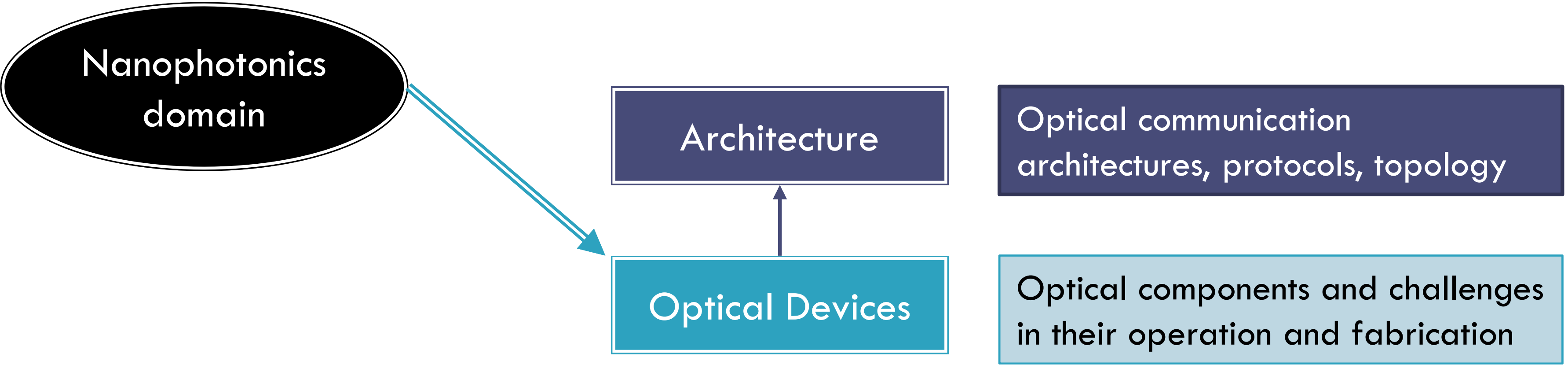
Nanophotonics domain

Optical Devices

Optical components and challenges in their operation and fabrication

OUR OPTICAL STACK



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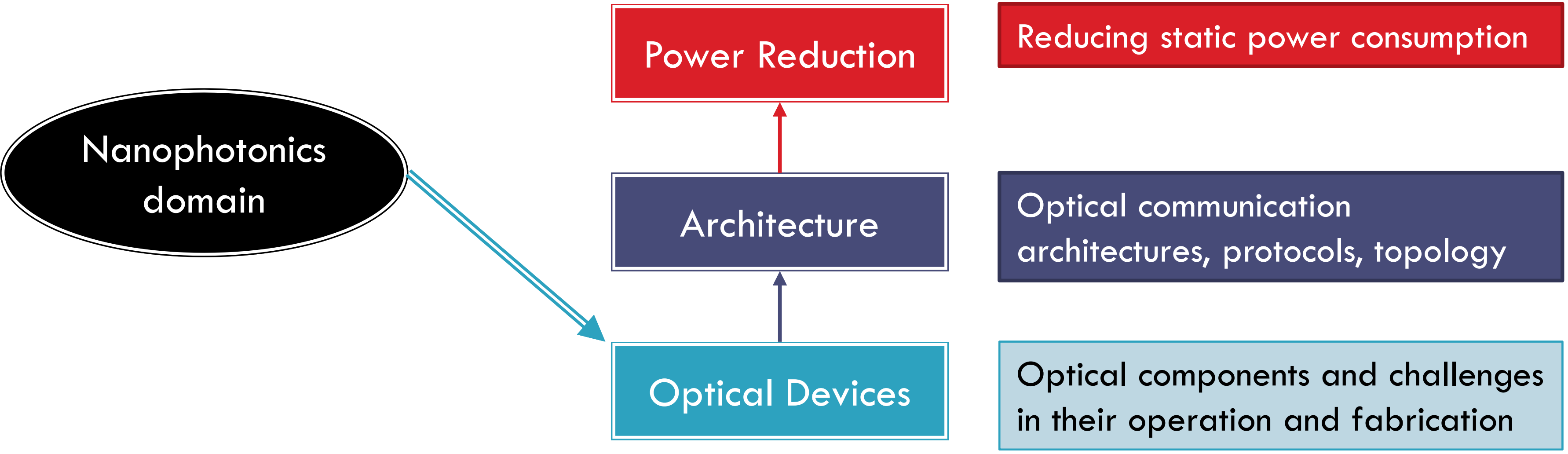

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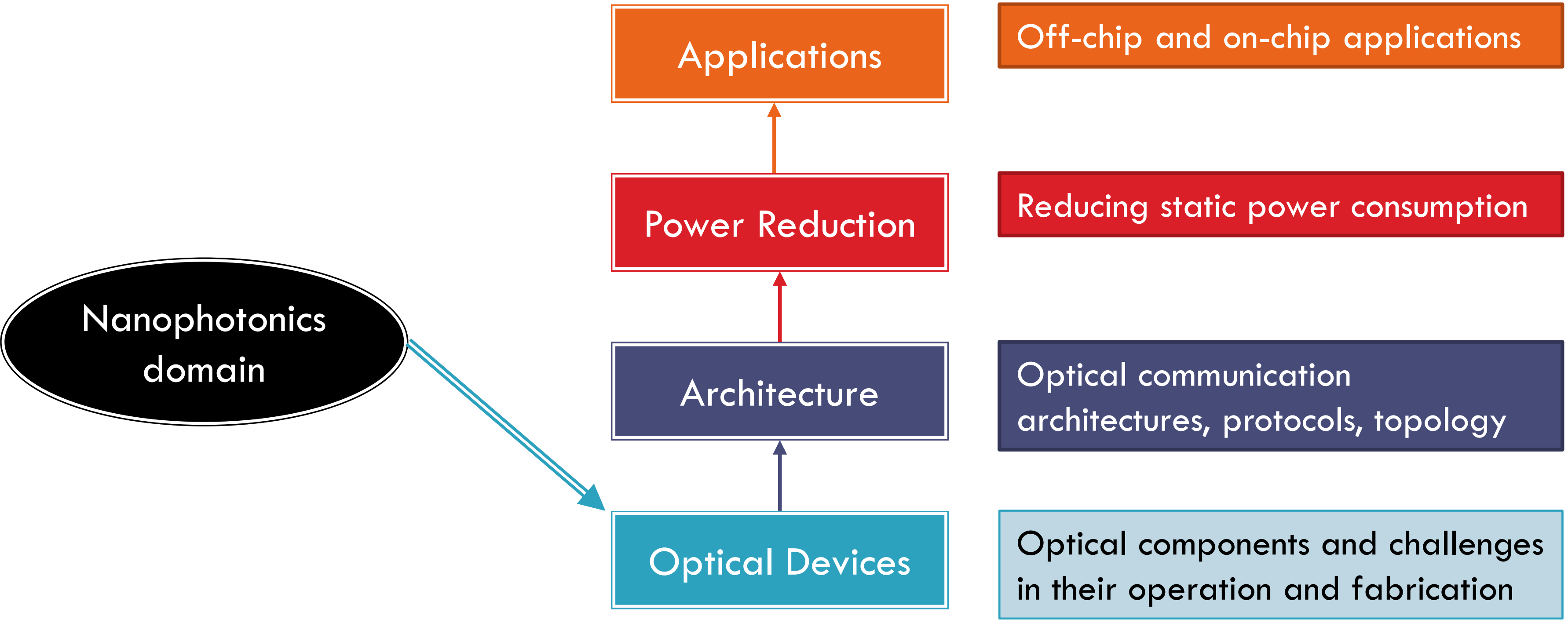
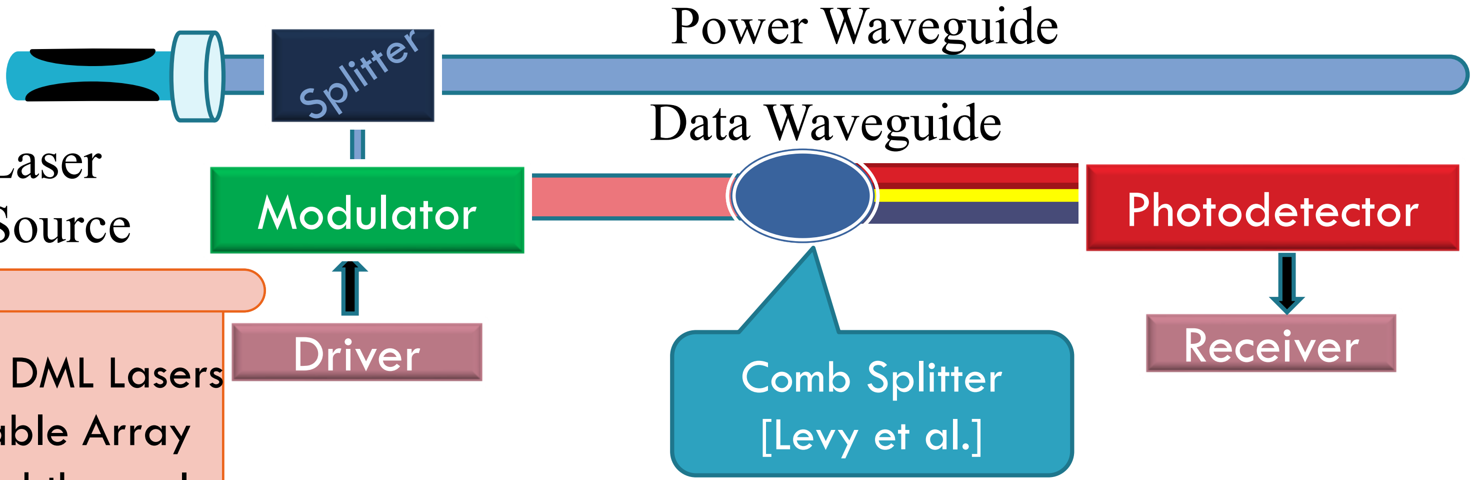


Basic Components of our Architecture

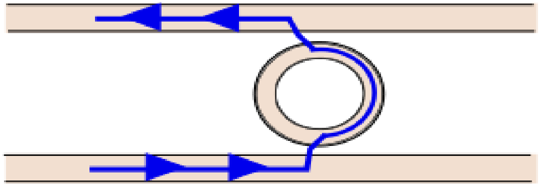
Optical Communication Framework

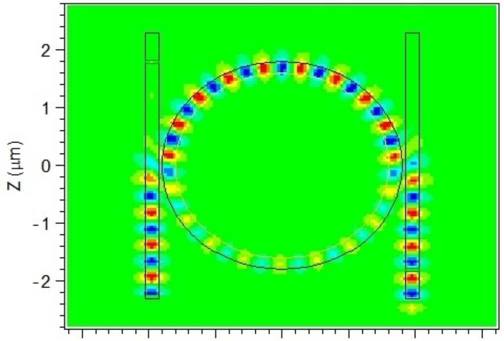


1. Fast DML Lasers
2. Tunable Array
3. Good thermal stability

Optical Devices: OptiKit

Ring Resonator : filters light, switching and modulation.





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VLSI Design ‘14

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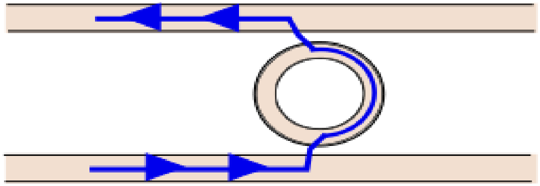

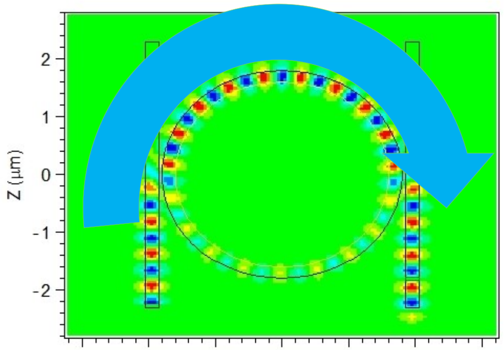

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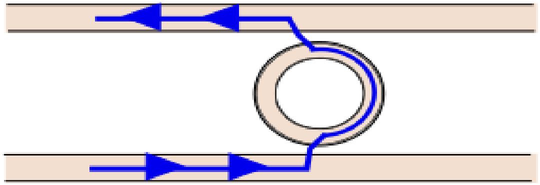

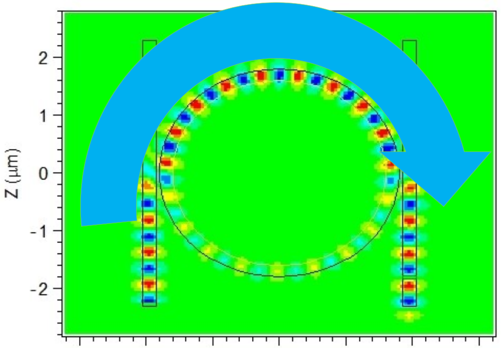

Splitters : split the light

- Multimode Interference
- Directional coupler
- Y Junction

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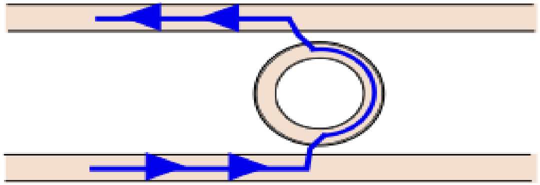
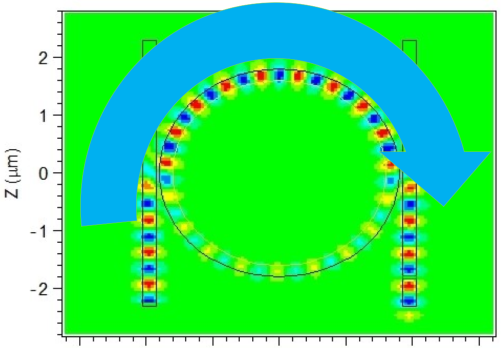




Splitters : split the light

Multimode Interference

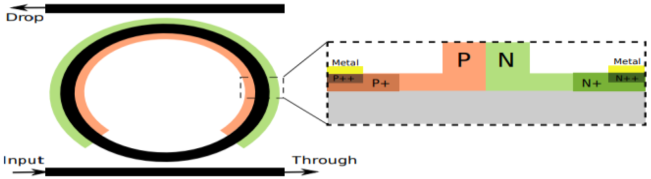
Directional coupler

Y Junction

Limitation : Fixed split ratio
High power losses

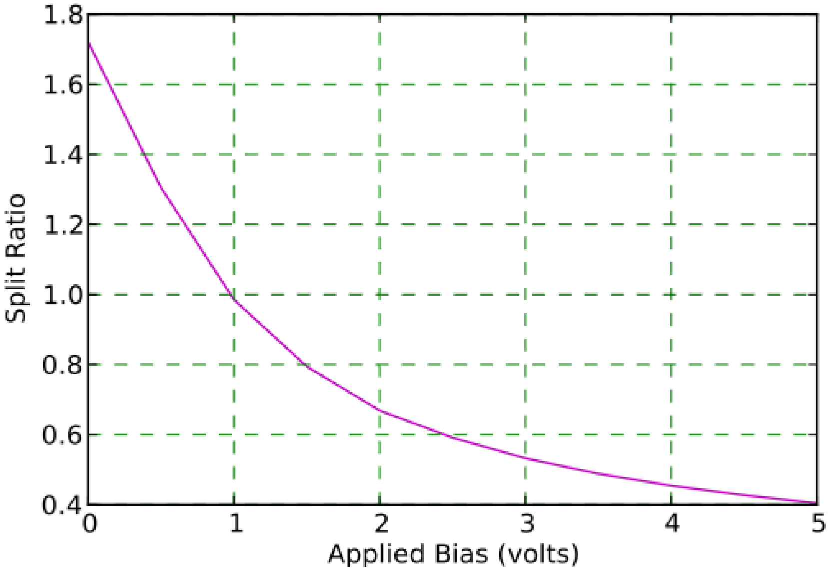
Required : Tunable splitter

Our Solution : Tunable splitter

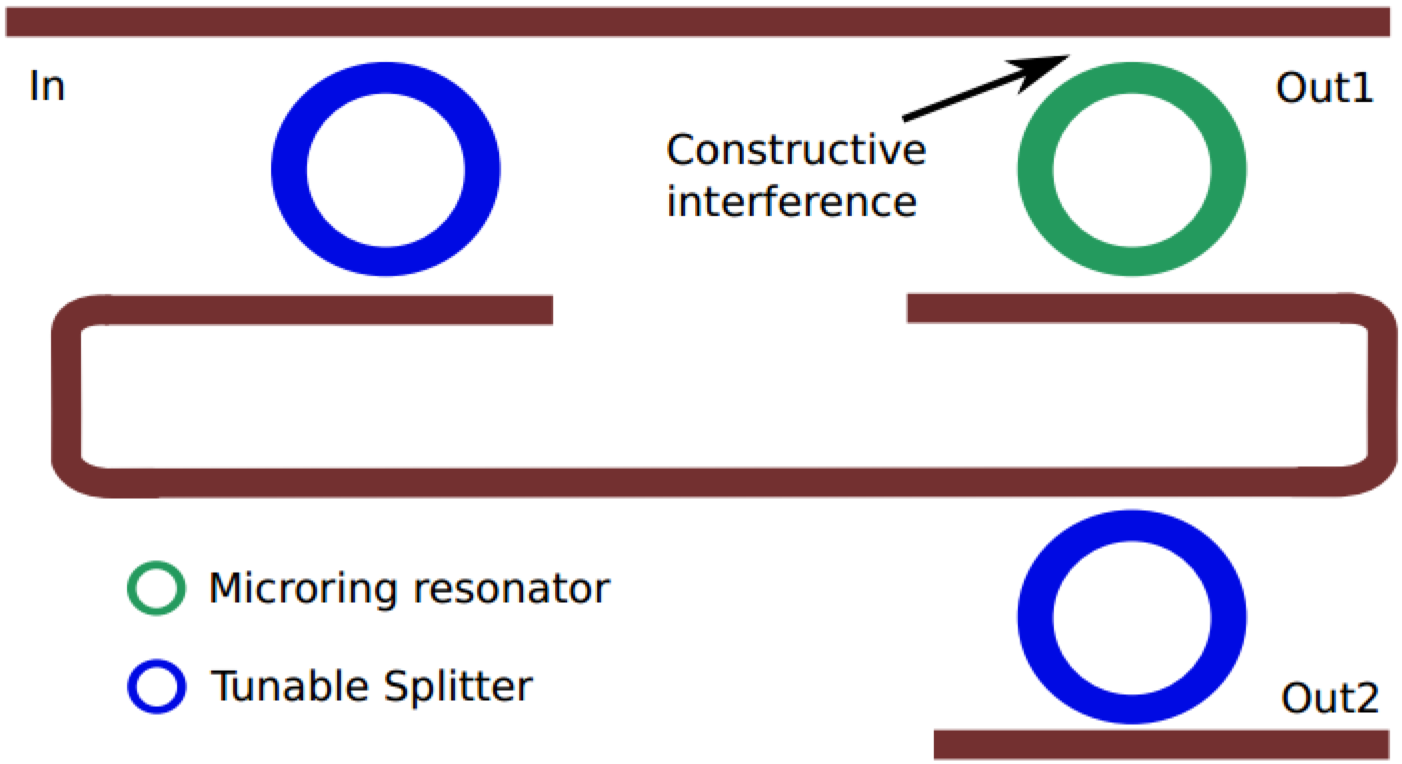


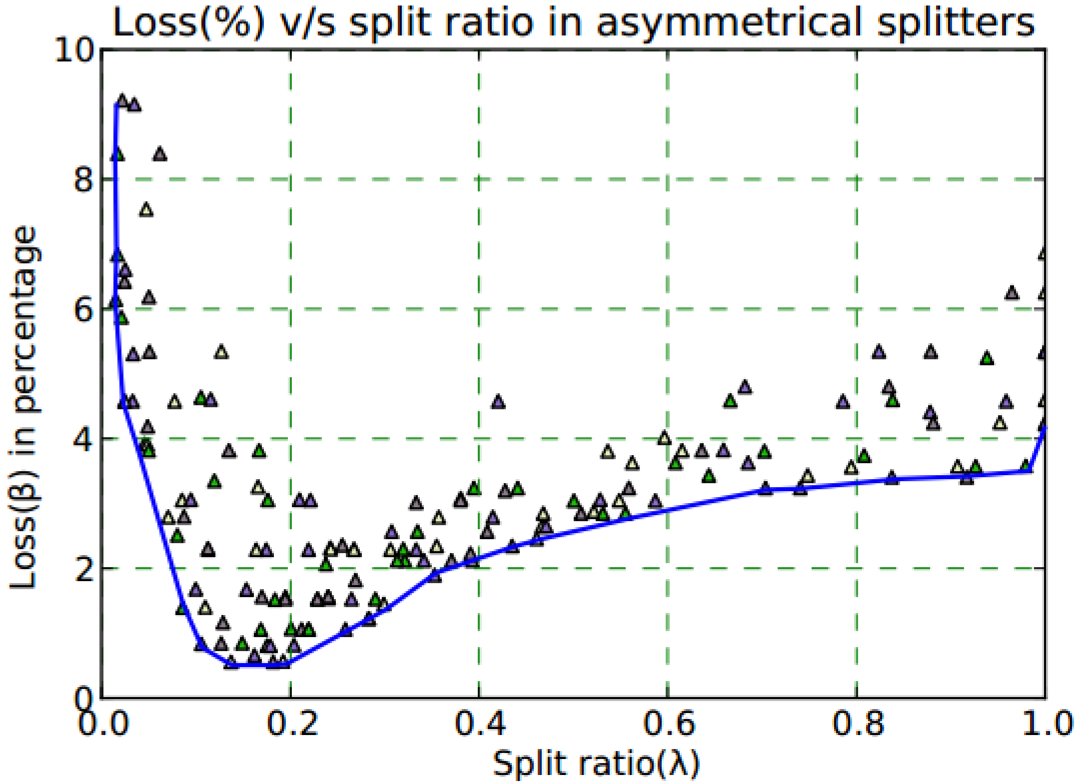
Optics Communications '16

- A tunable power splitter which can be tuned on demand.
- Idea : Allow ring resonator to work in partial resonant states.
- Change the refractive index of ring resonator.
- How : Thermo-optic and Electro-optic effects.
- Achieved tuning ranges from 0.4-1.8.
- Proposed an algorithm to compute the optimal split ratios [SiPhotonics '15].
- Currently working on wide tuning range splitter and broadband splitters.



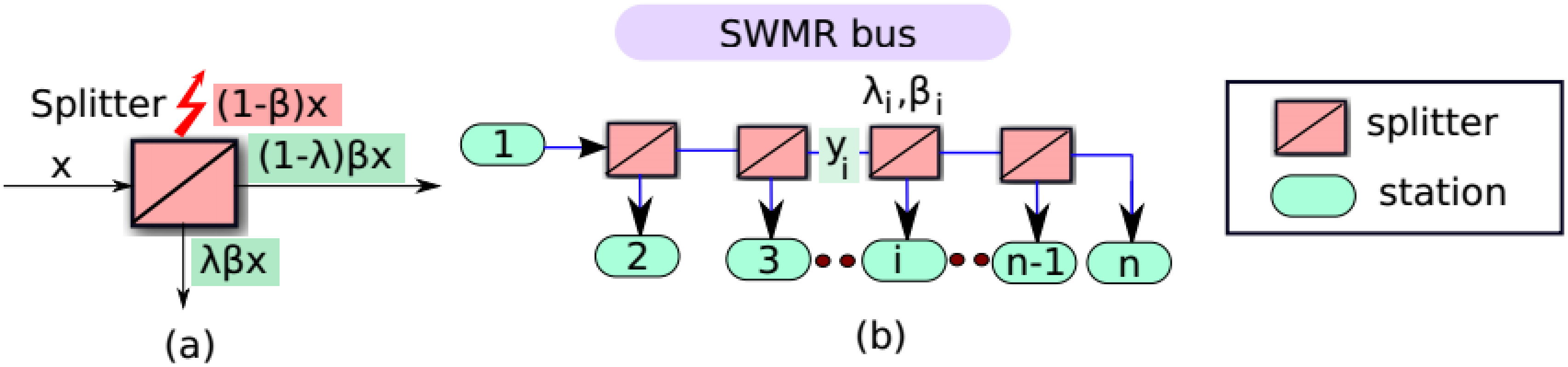
Simple Approach for Extending the Split Ratio Range





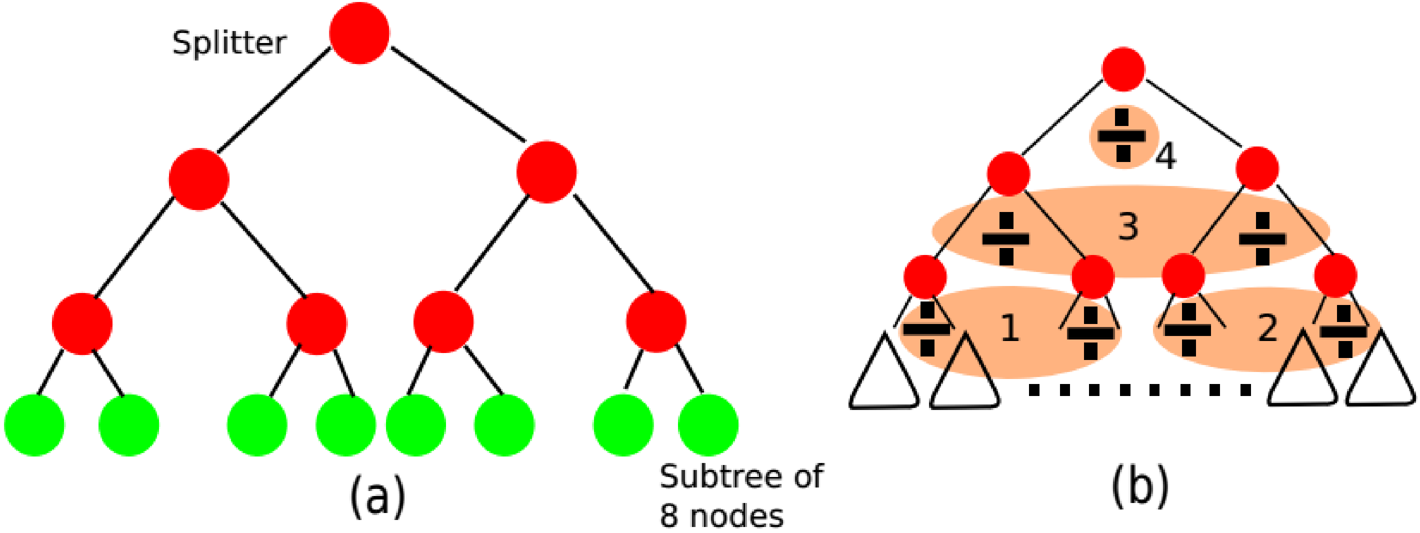
The loss varies with the split ratio

Splitters in Series



- The loss is a function of the split ratio
- Proposed an $O(N)$ time algorithm for computing the optimal split ratio
- Very fast implementation in hardware using lookup tables

Optimal Split Ratio for Trees



- O(N) time algorithm
- Takes 32 cycles (@2.5 GHz) for computing the optimal configuration

Optical Devices : Challenges

Challenges

- **Fabrication Challenges**
  - Process variations
  - Design and integration
- **Operational Challenges**
  - Temperature variation
  - Charge density variation

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Extend the Varius Toolkit for Optical Networks

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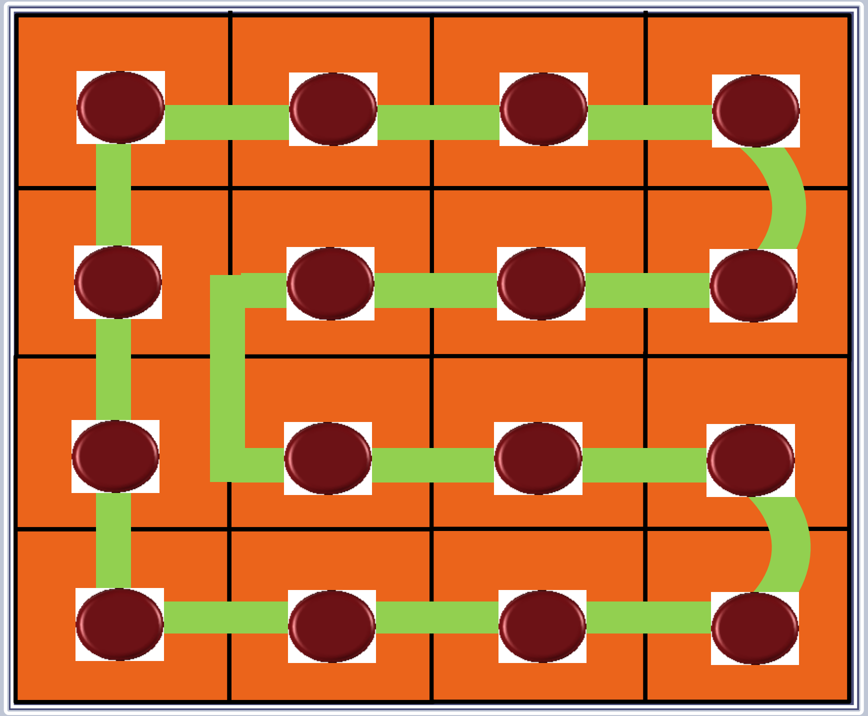

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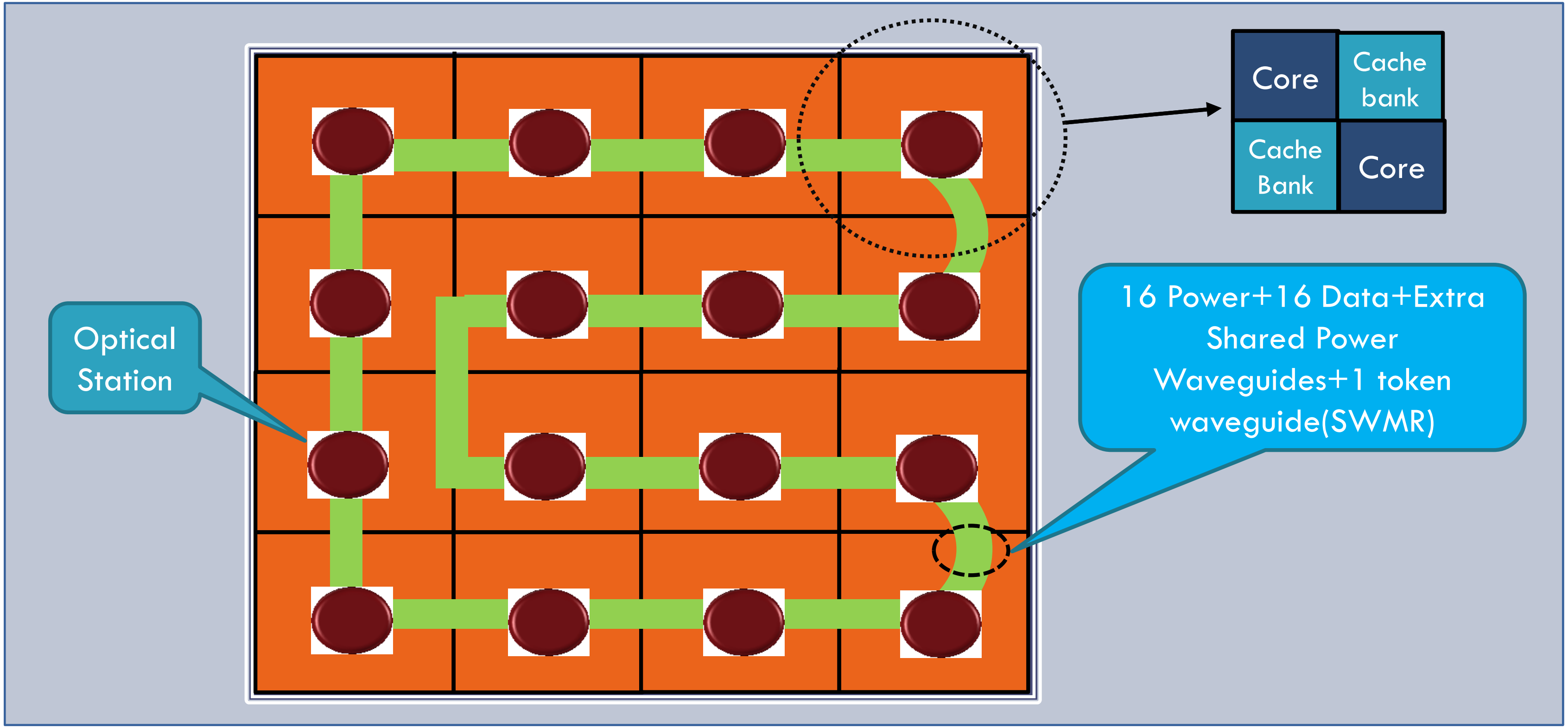

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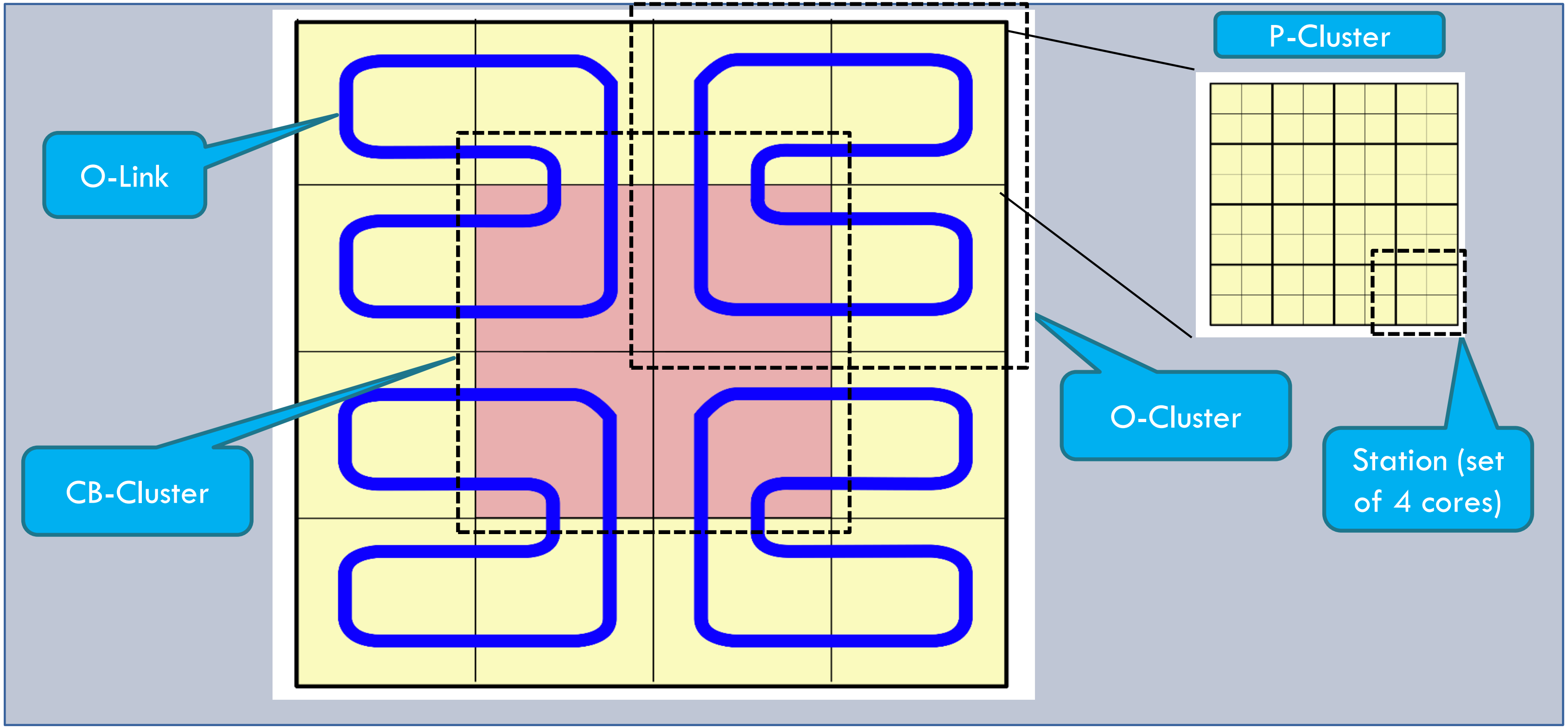

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- ❑ Proposed an optical architecture for a multi-chip design : NUPLet [ICCD '17].

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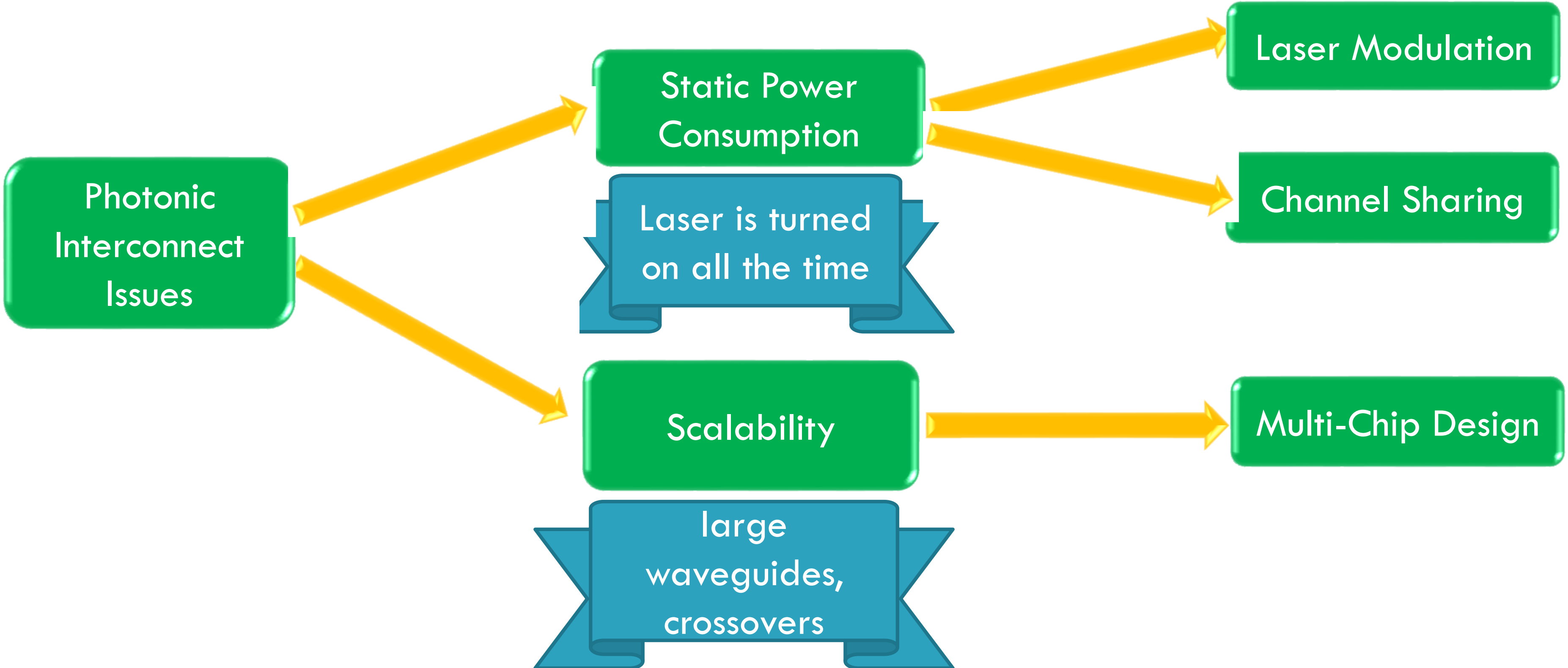
    - Wavelength Routing using resonators.

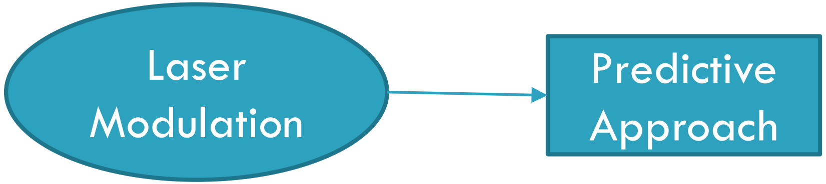
Power consumption and scalability



Our Solutions

Laser Modulation

Our Solutions



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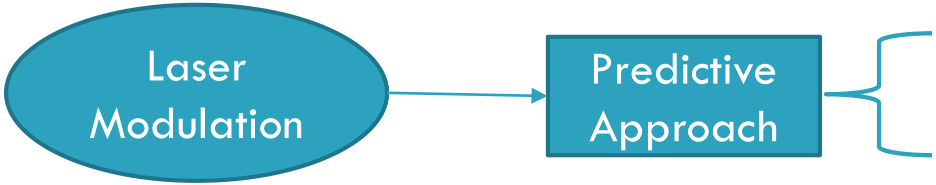

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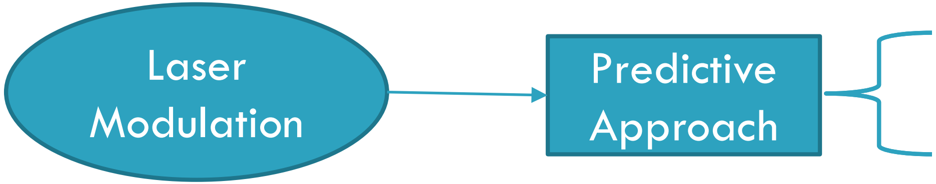

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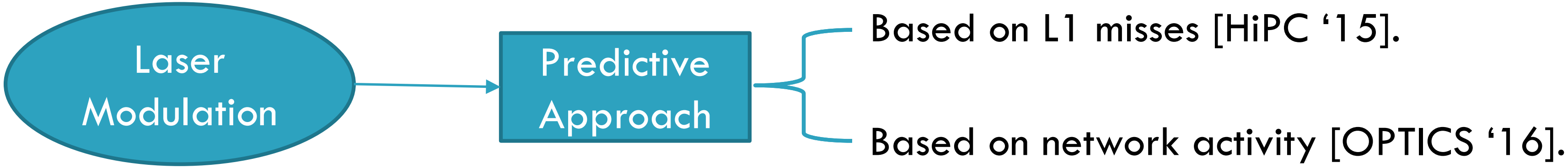

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- Based on L1 misses [HiPC '15].
- Based on network activity [OPTICS '16].

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- NUPLet: An architecture for multi-chip system [ICCD ‘17].

Applications

Applications of optical interconnects

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Cache Coherence

Optical Broadcasts

Optical tokens for shared cache lines

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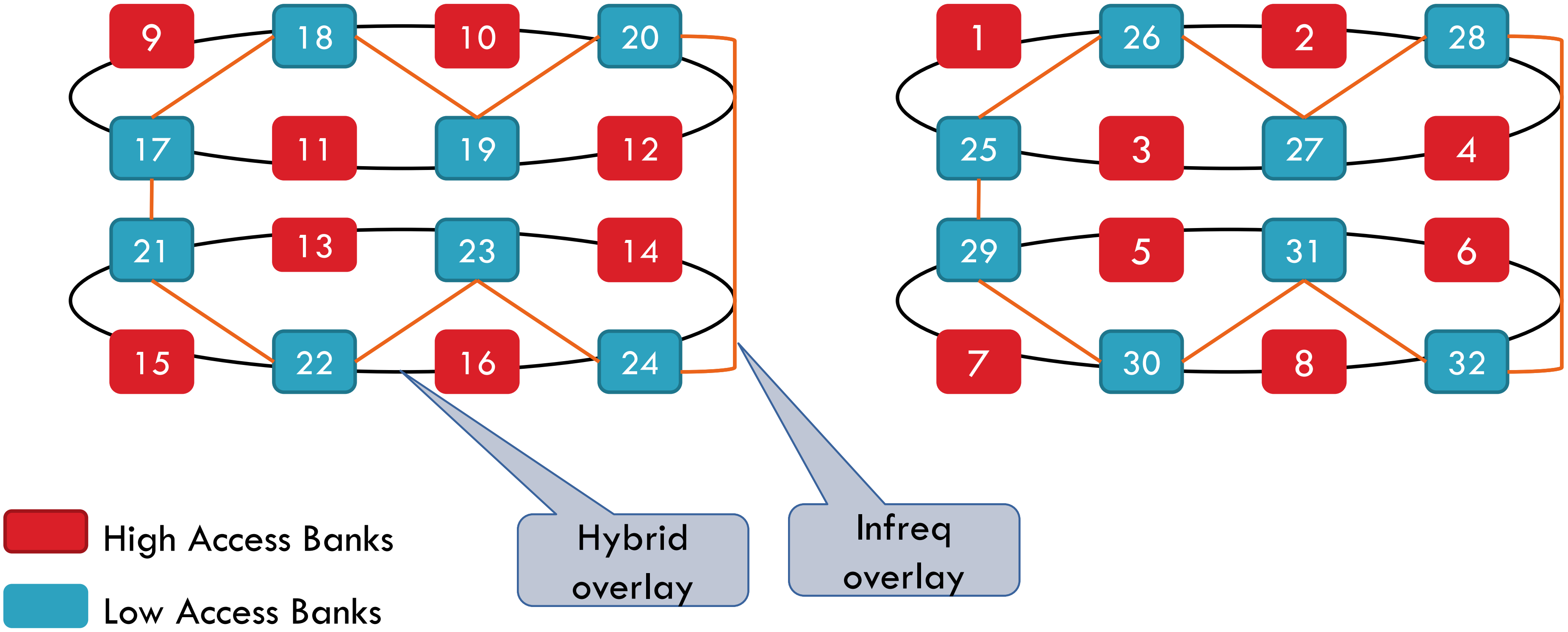
    - Broadcast in an overlay [ACM JETC'17].
  - Virtual Chip
    - Connecting various smaller chips.
    - Optical communication for inter chip messages

Optical NUCA (Non-uniform Cache)

- Traditional NUCA divides banks into bank sets because of wire delays.
- Bank sets are arranged as columns.
- However, optical networks allow us to freely choose banks in the bank set. → Low latencies
- Each bank set is called an overlay. → virtual network
  - Logic for creating overlays: homogenize the number of accesses
  - Minimize contention

Overlay Formation

HiPC '14, ICCD '17, ACM JETC '17



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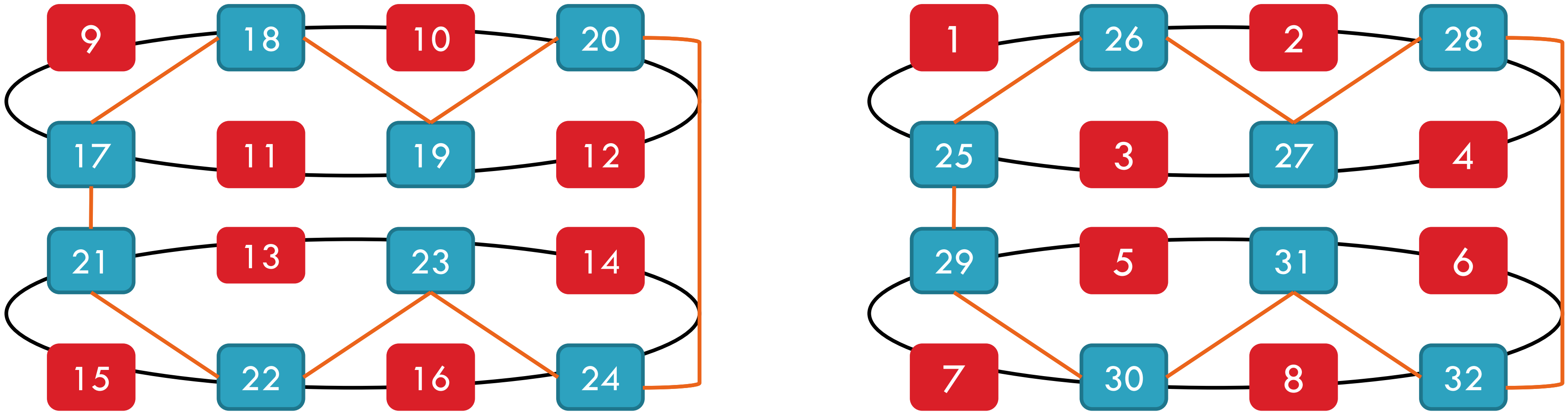

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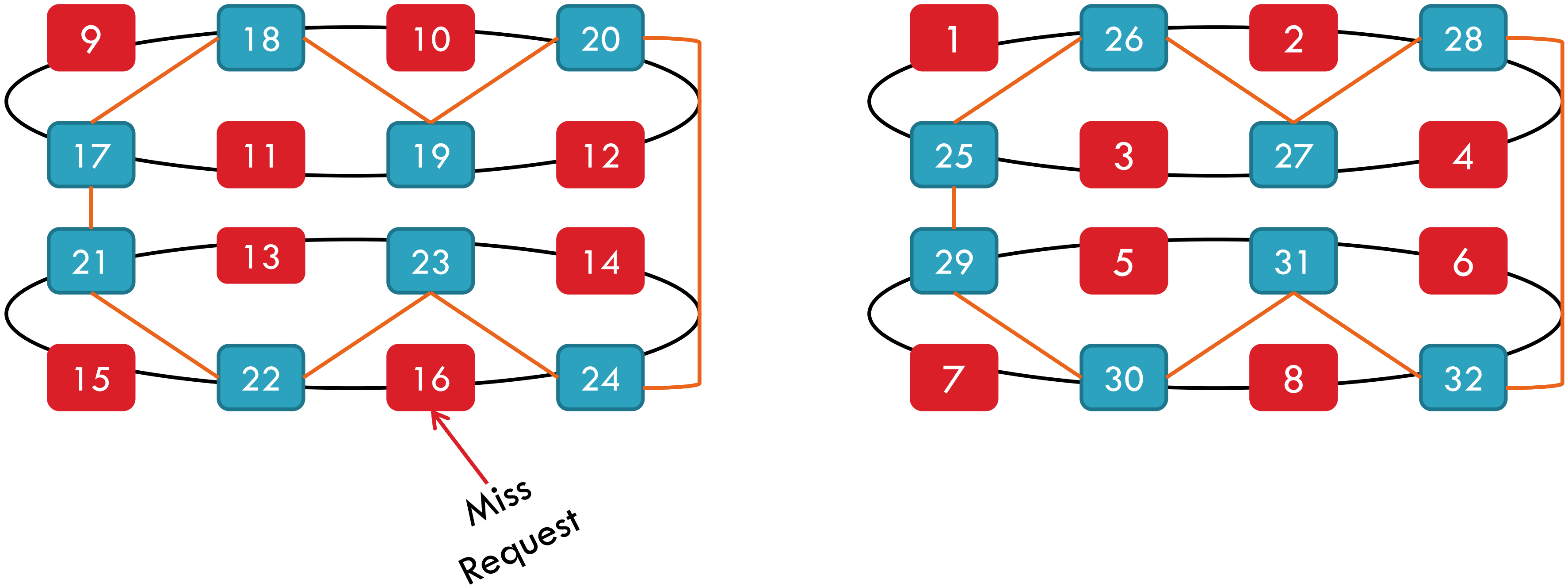

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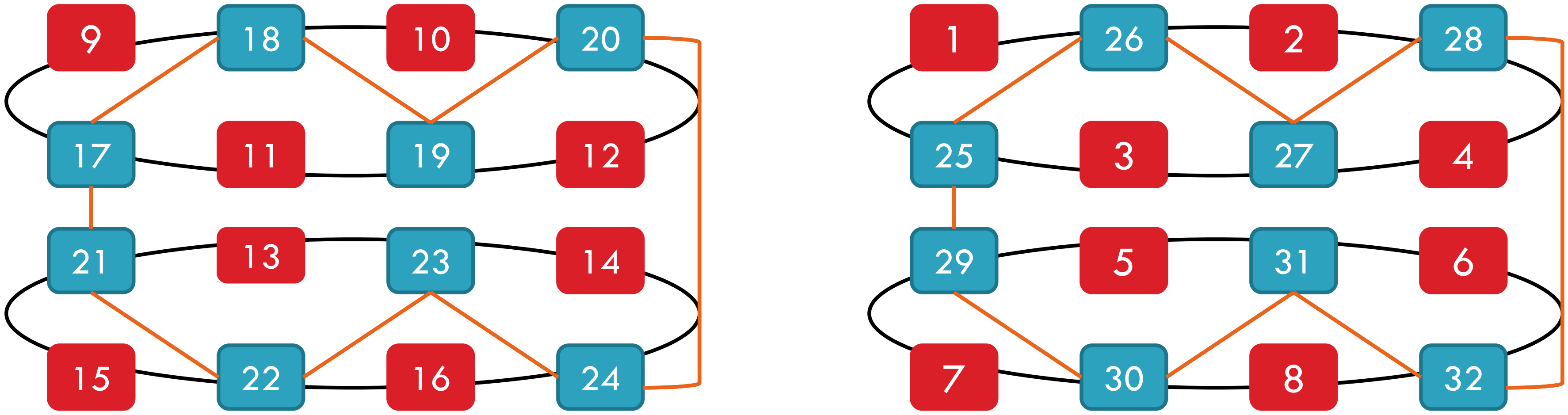

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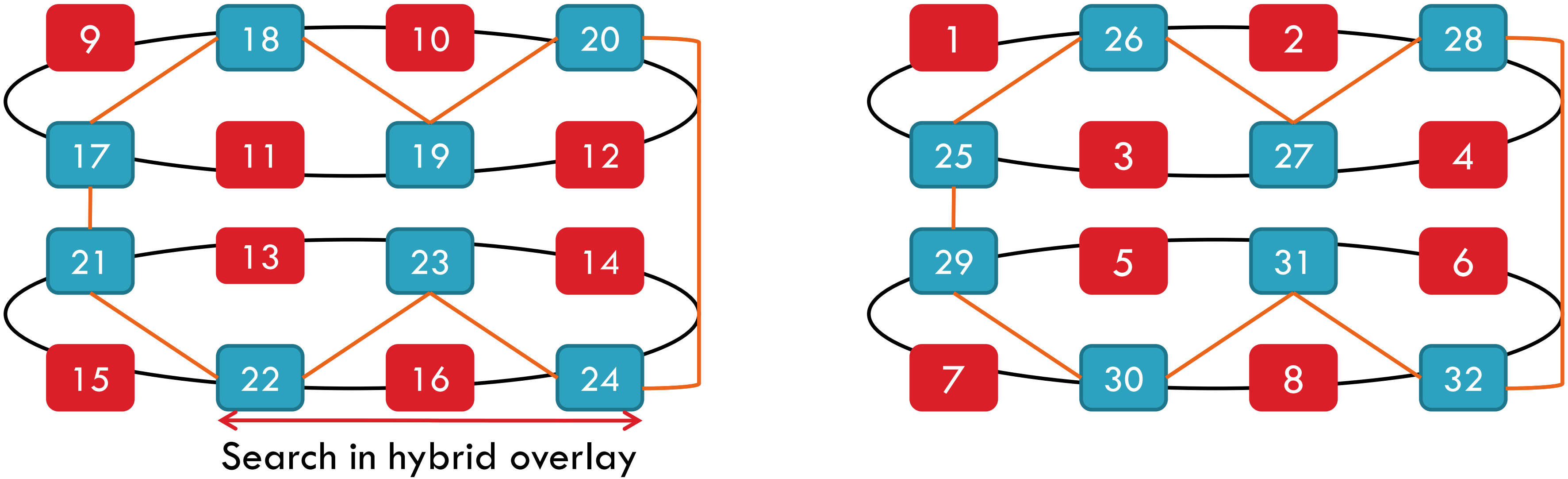

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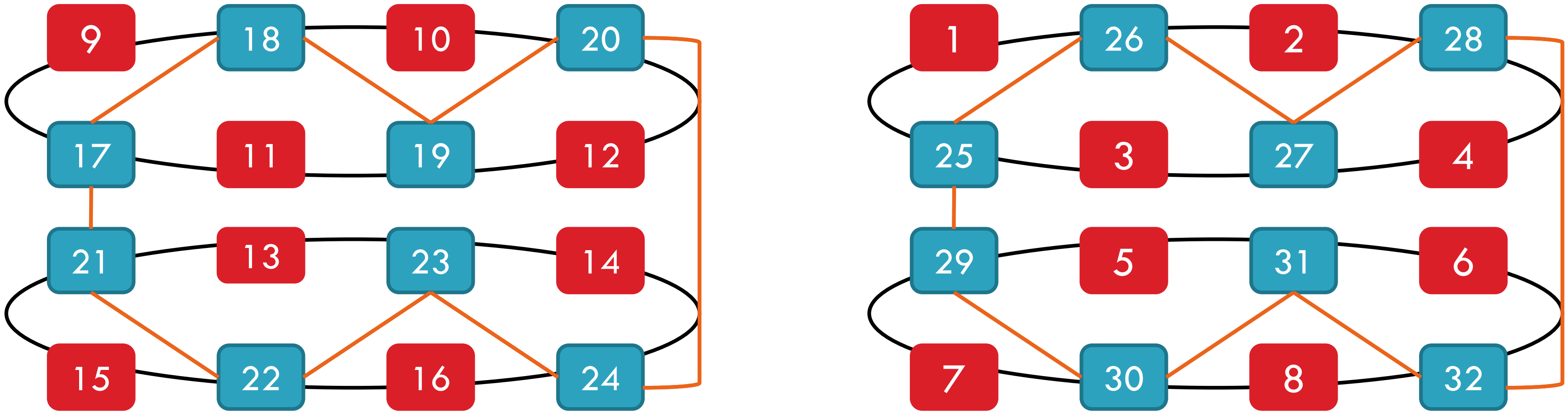

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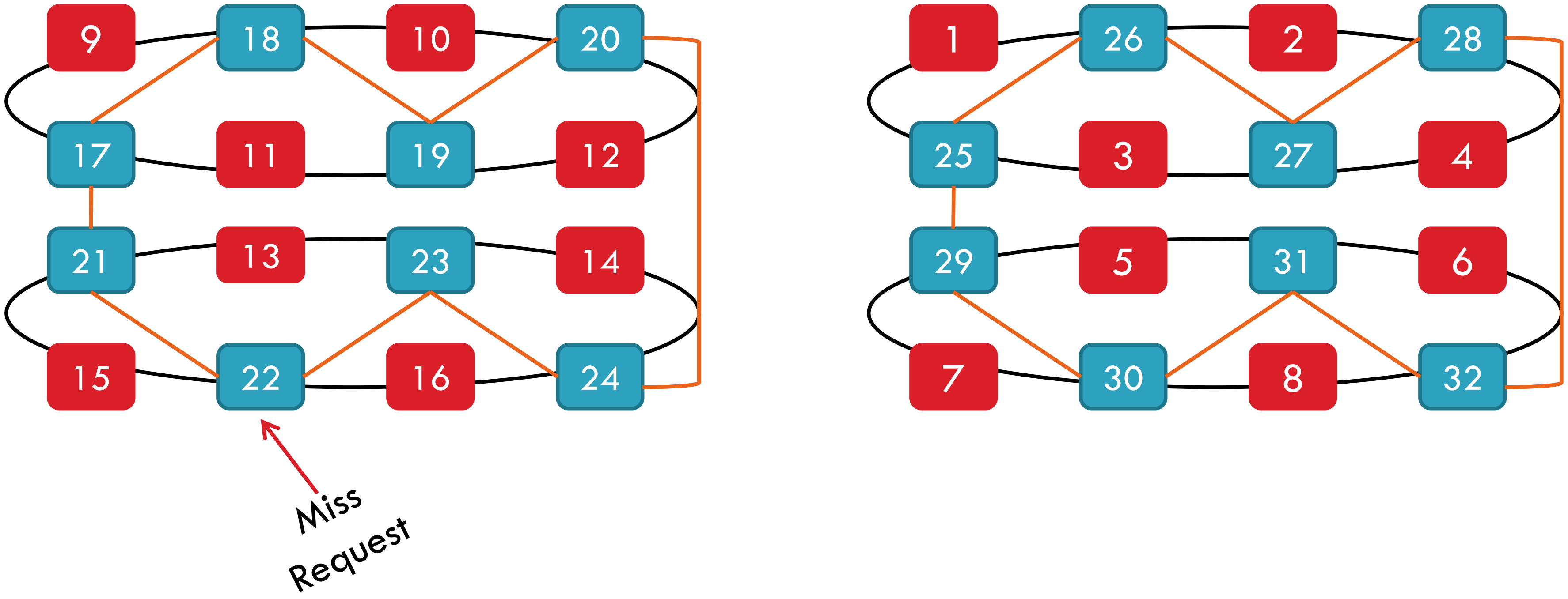

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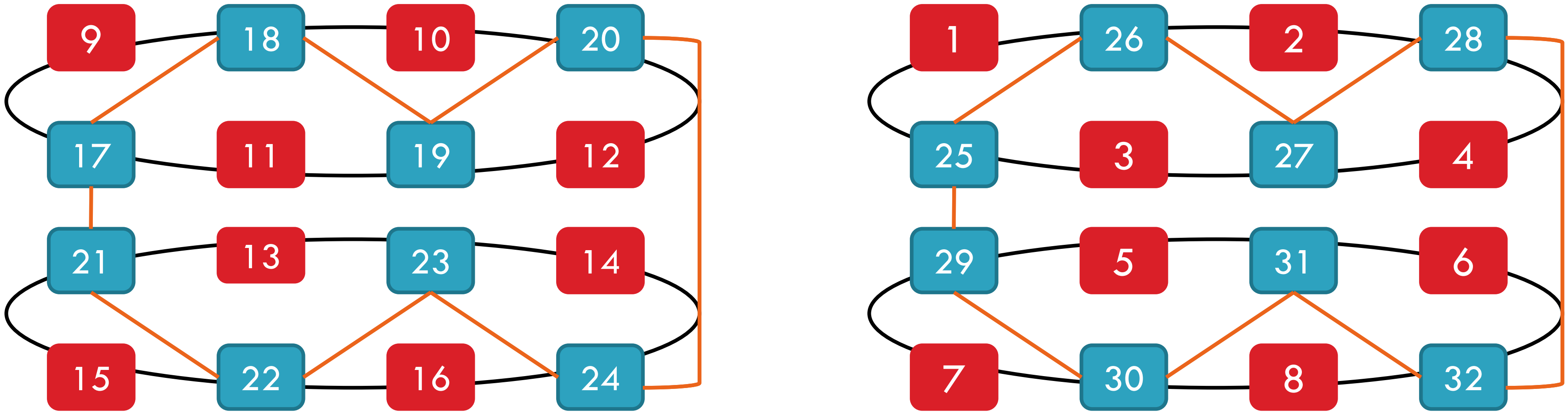

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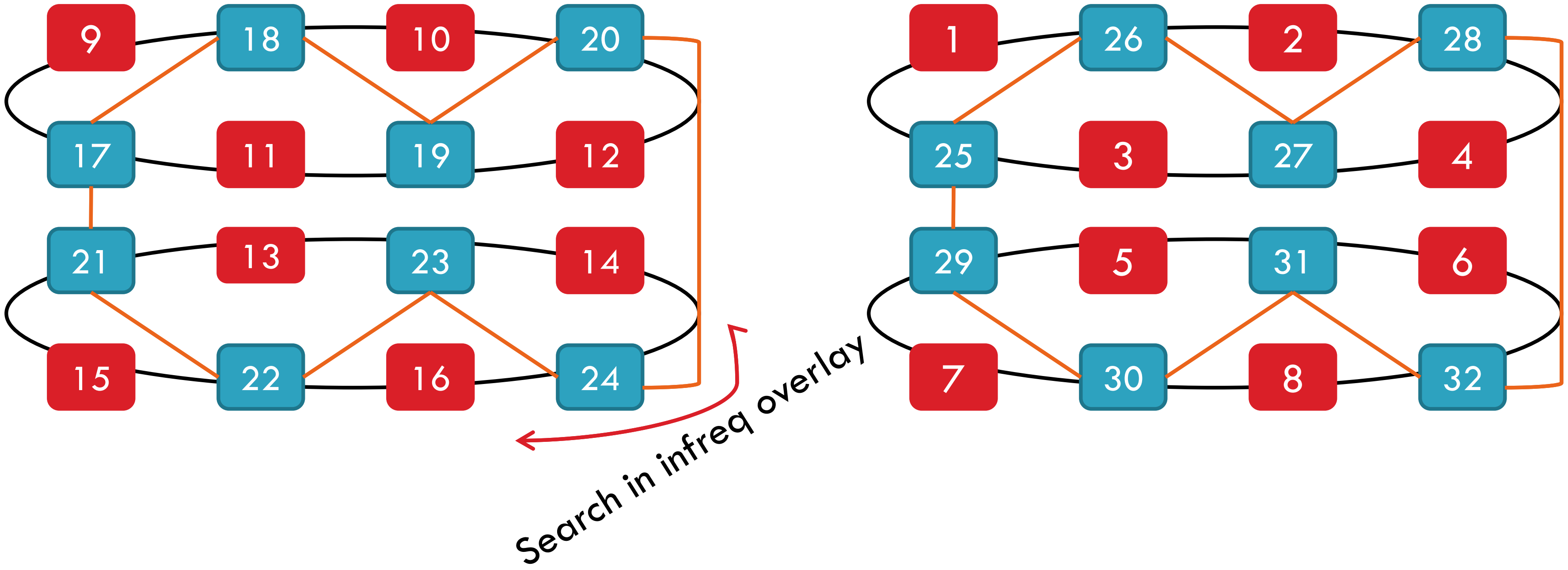

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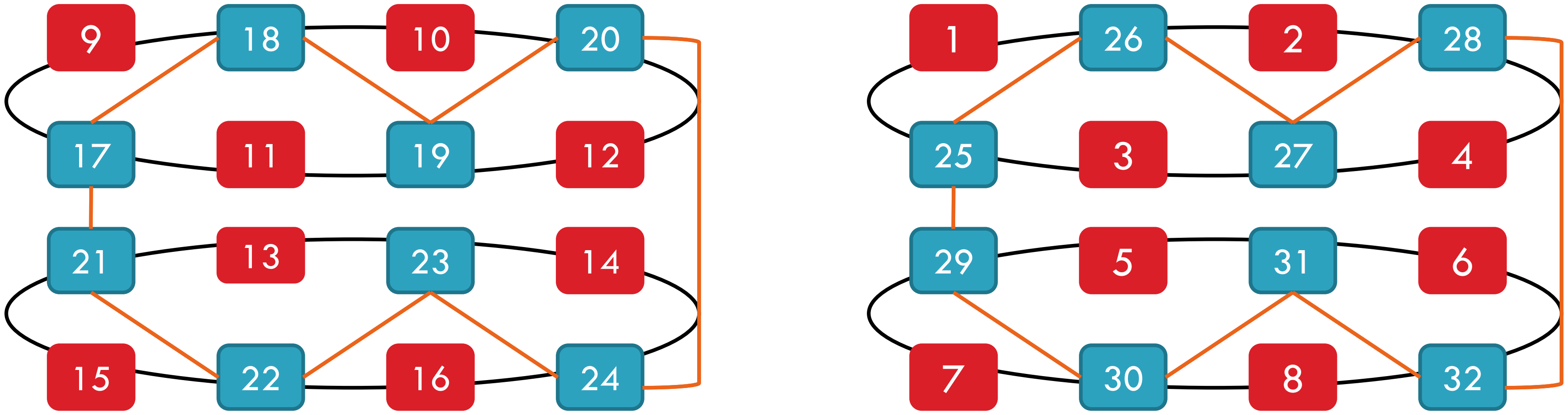
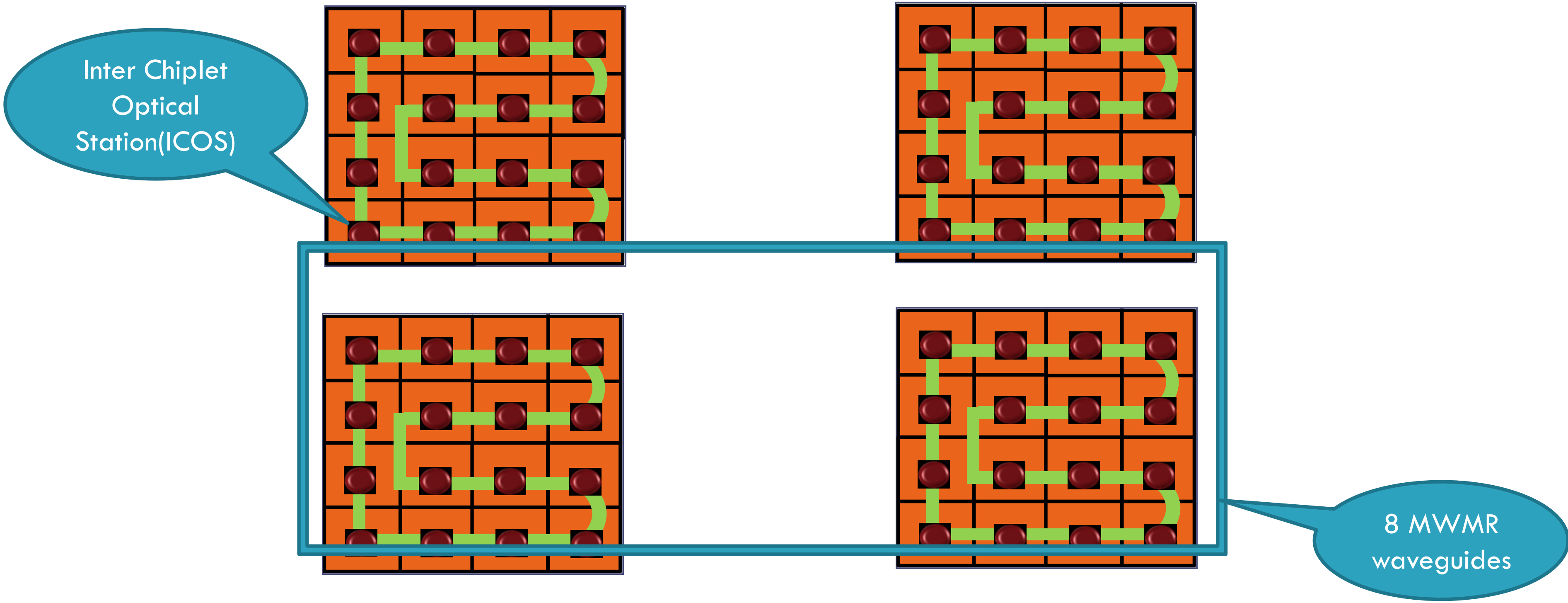


NUPLet : NUCA over chiplet

- A Virtual Chip.
- Scalability : Separation of intra and inter chiplet networks, resulting in a scalable architecture for multi-chip designs.
- Reduction in Inter Chiplet Messages : Implementation of a NUCA scheme.
- Power Consumption : A novel prediction mechanism to reduce power consumption of multi-chip networks.

NUPLet Architecture



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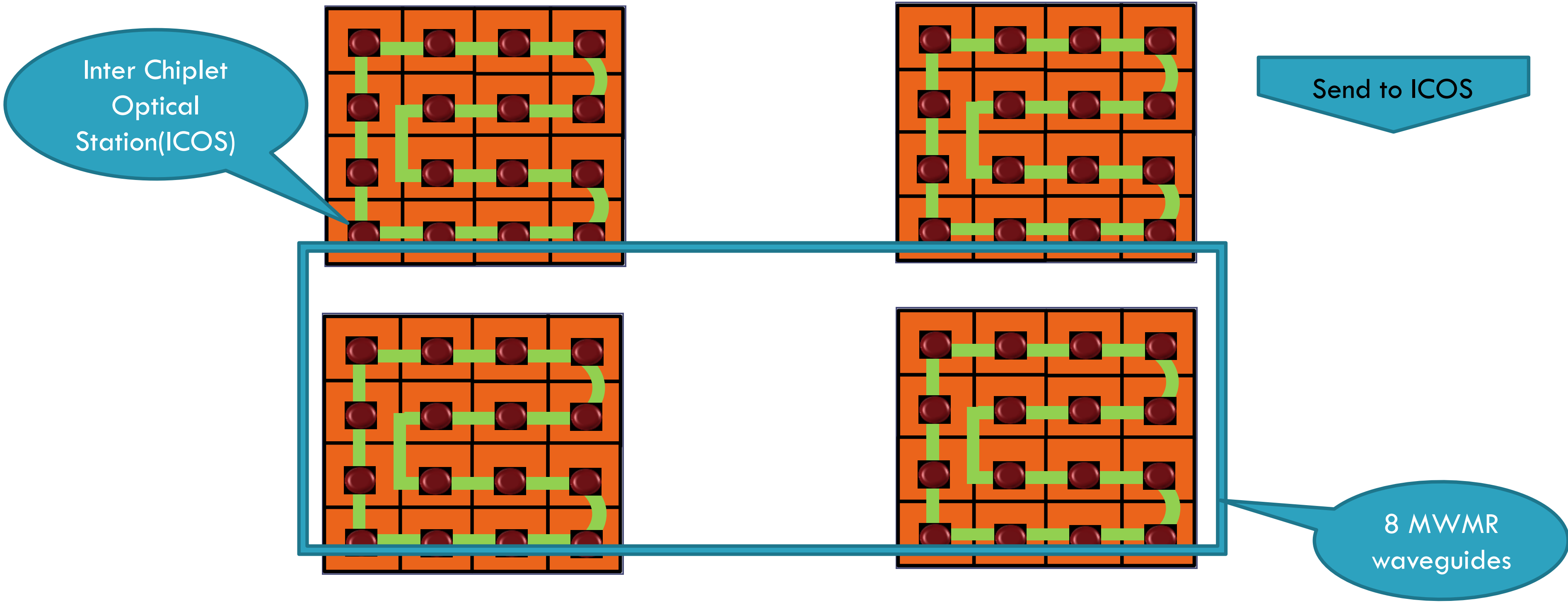

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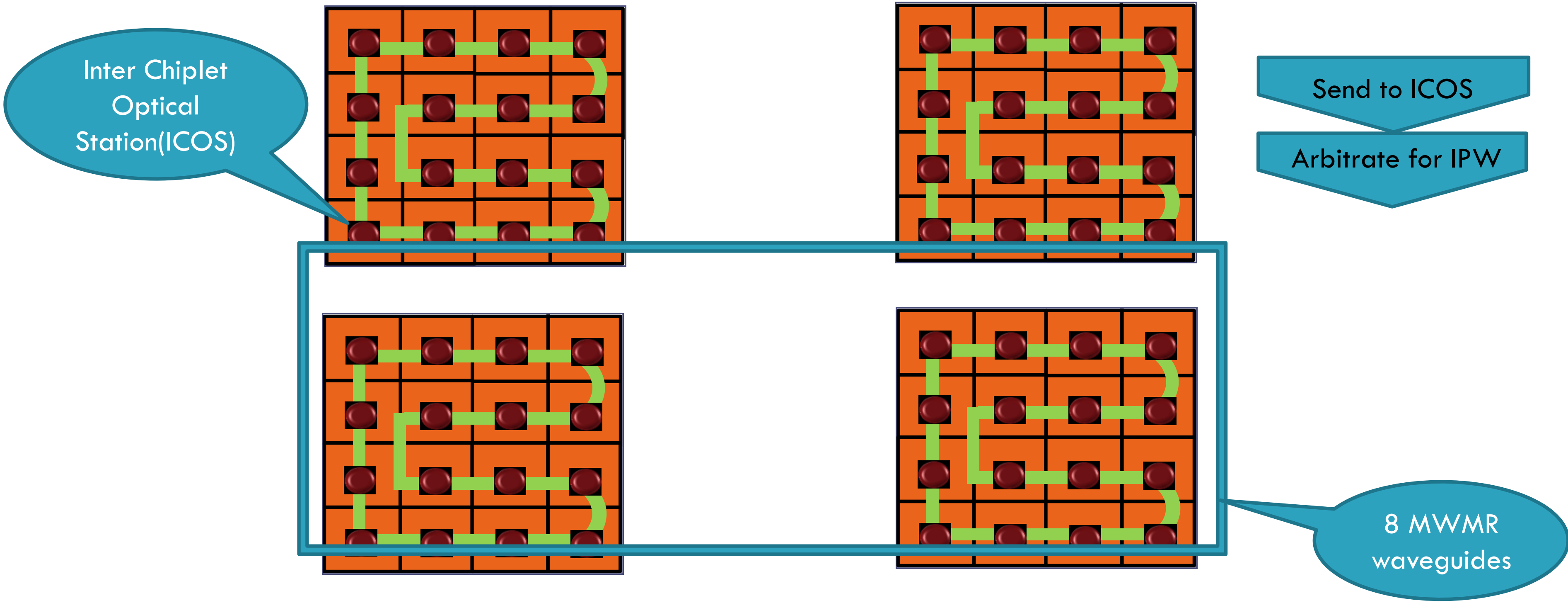

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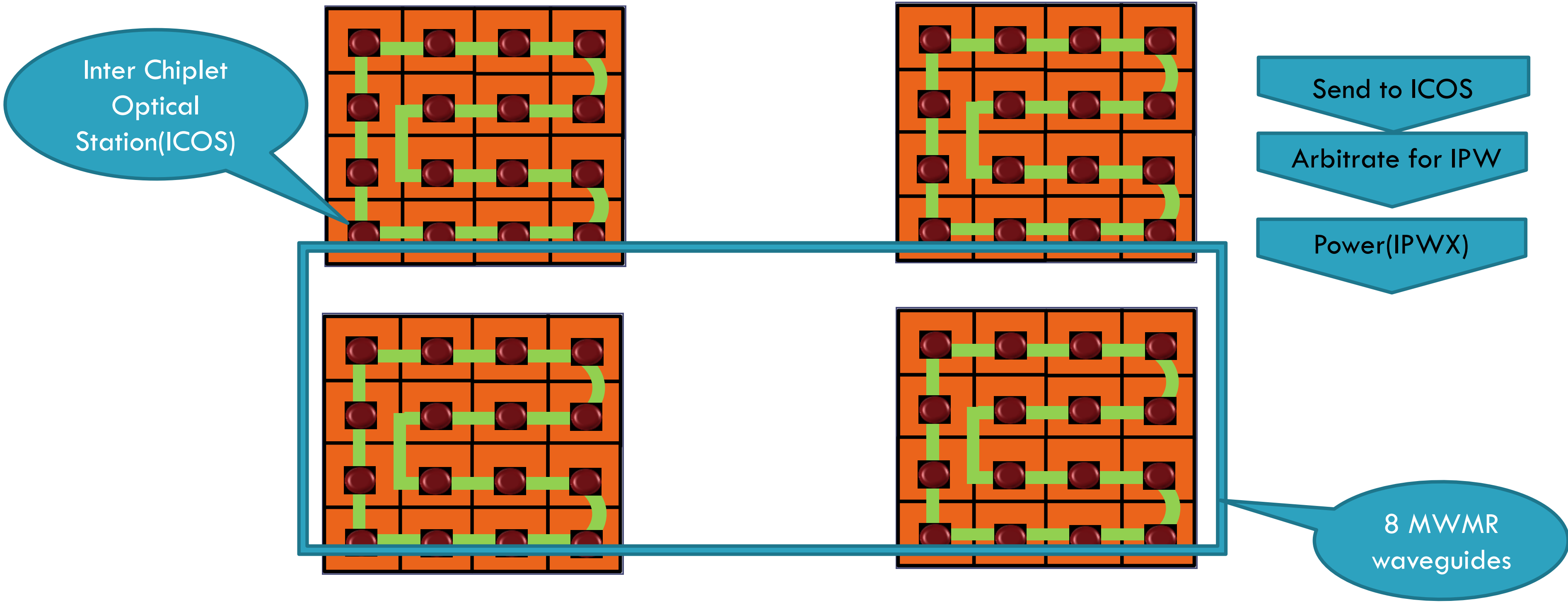

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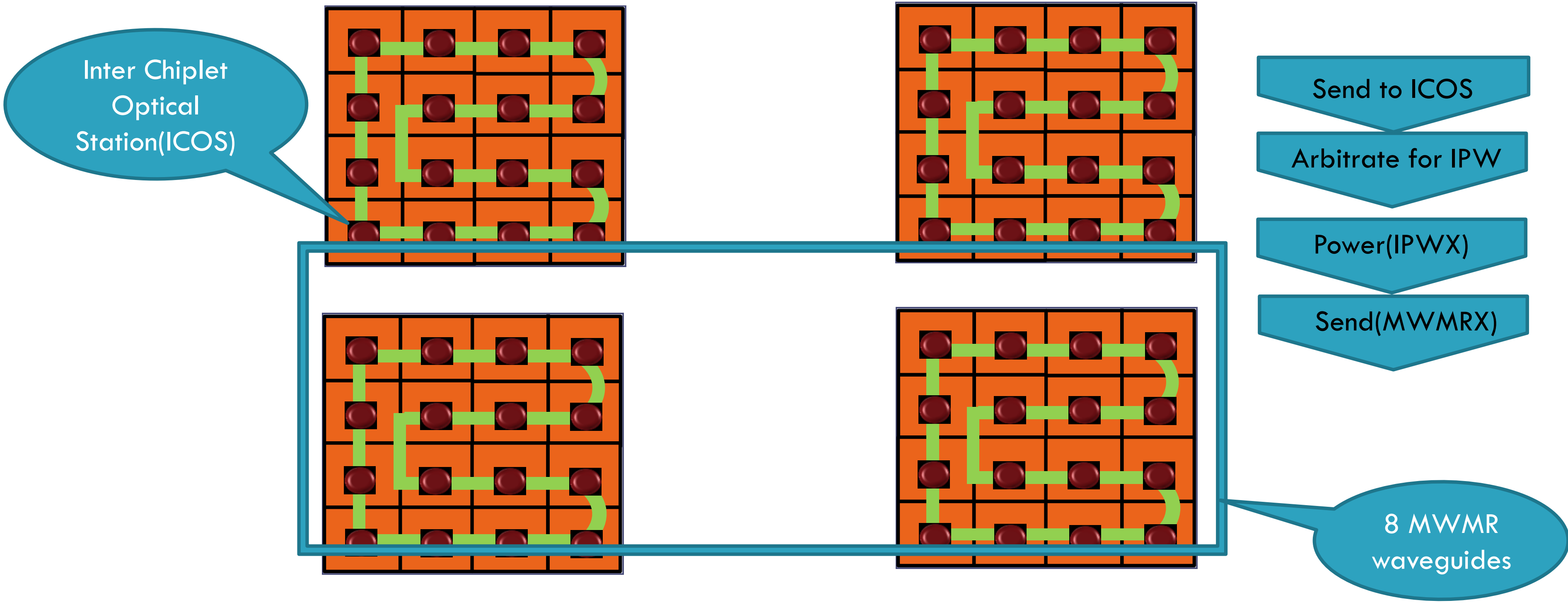

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- Static power consumption is still 3X more than the ideal power required.


THANK
YOU