A Force-Directed Placement Algorithm for 3D Optical Networks-on-Chip

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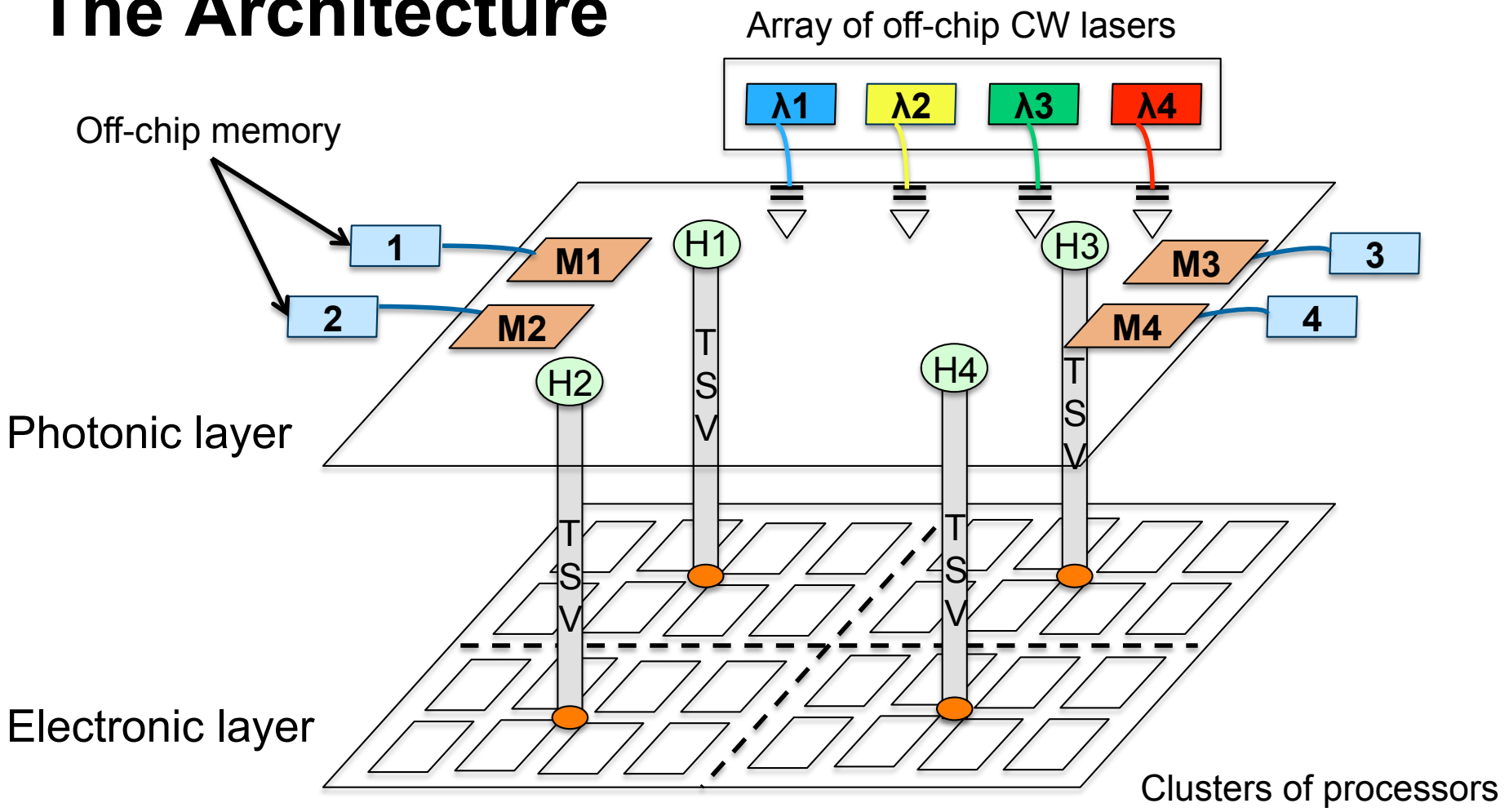
Outline

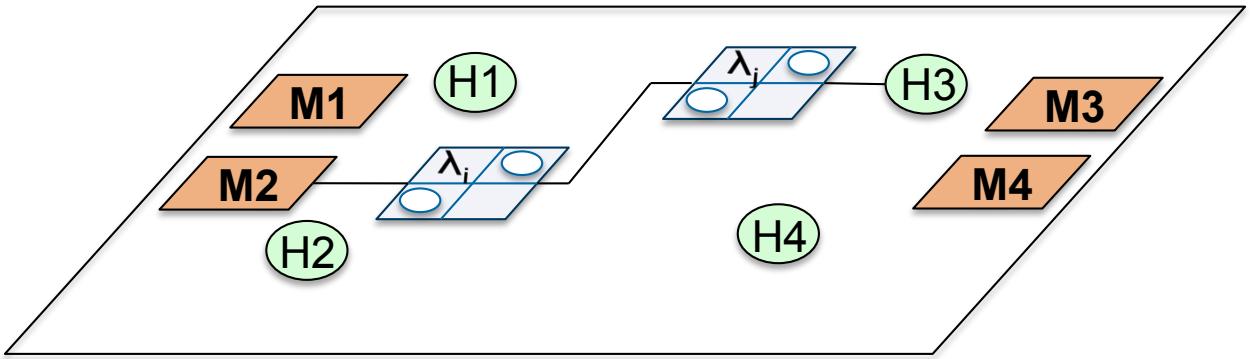
- Introduction
- Placement and Routing Tools for ONoCs
- Force-Directed Placement
  - Initial Placement
  - Global Placement
  - Legalization
- Experimental Results
- Conclusion

The Architecture

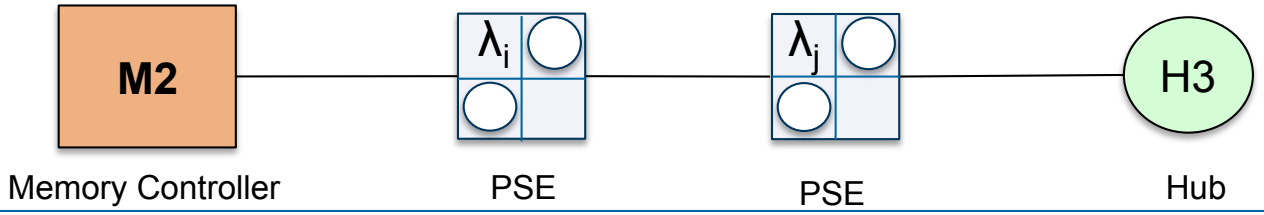


The Photonic Layer

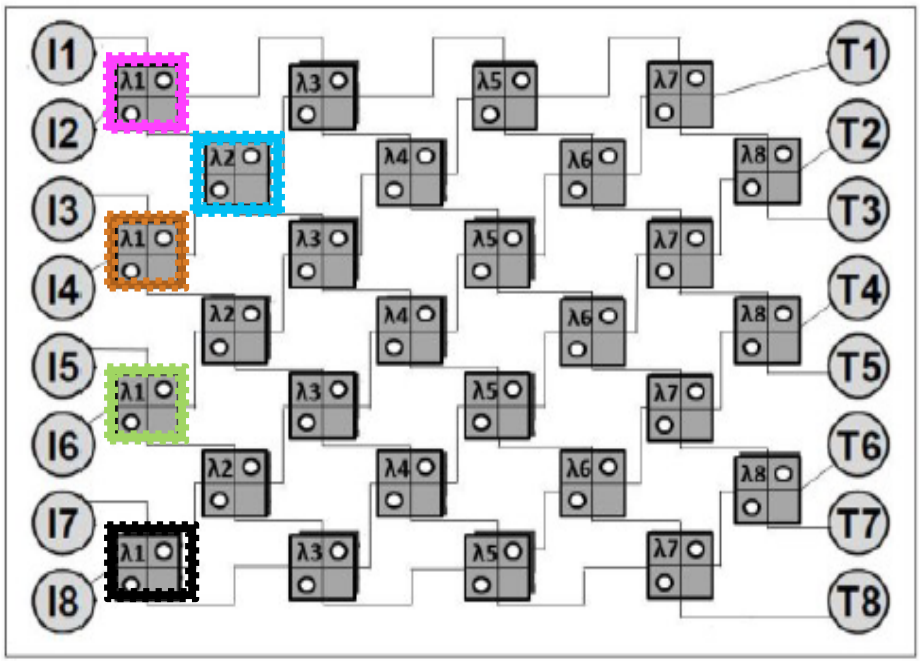
Photonic layer



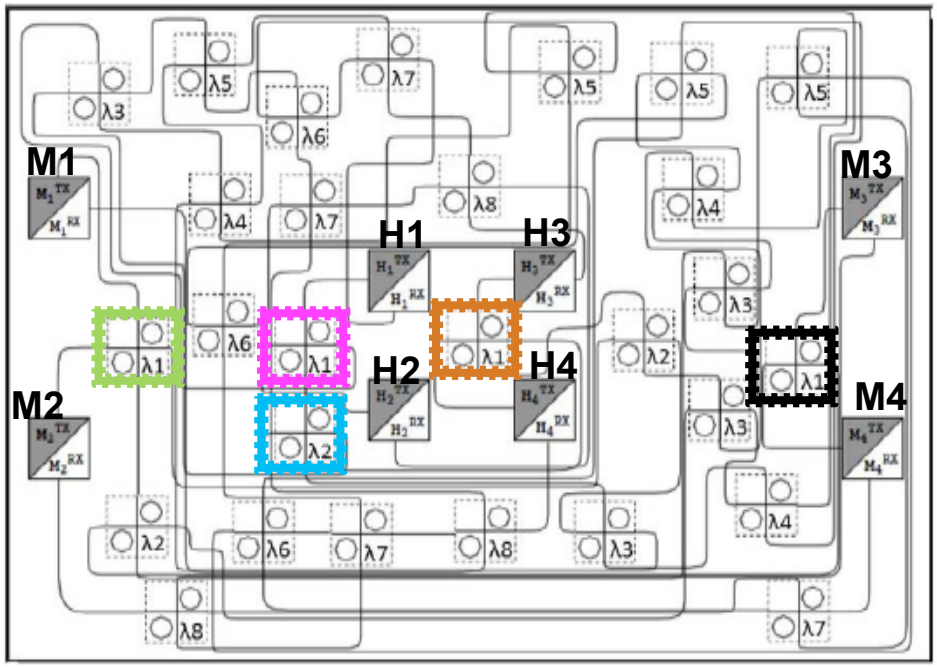
- A **path** connects two Hubs or a Hub and a Memory Controller via passive Photonic Switching Elements (PSEs) and waveguides



Logic Scheme vs. Physical Design



Logic Scheme



Manually created layout
[Ramini NOCS'12]

Creating layout manually is time consuming, error prone and suboptimal

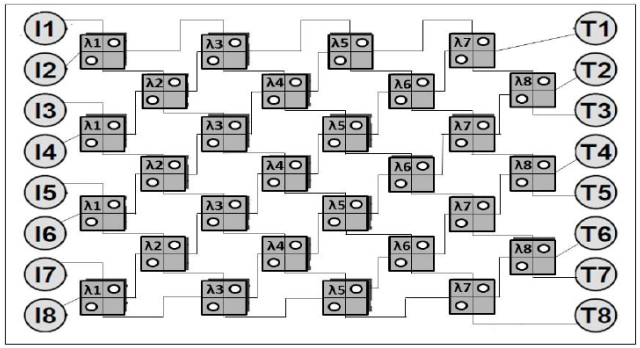
⇒ Automatic place & route tool for optical NoCs are needed

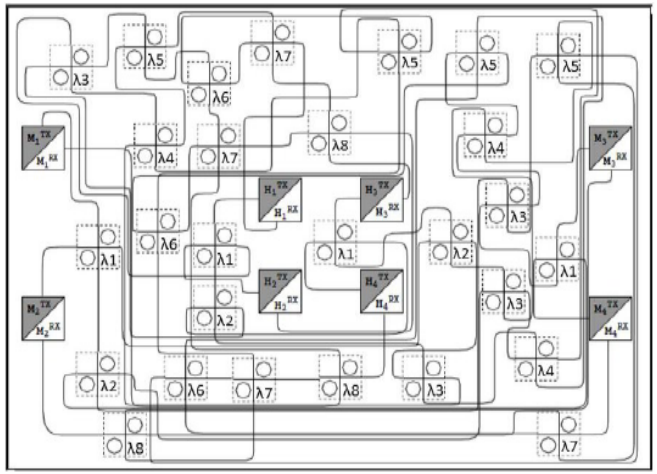
Placement and Routing Problem

Netlist, chip area, positions & dimensions of hubs and memory controllers

- Minimize **maximum insertion loss** over all paths, e.g. minimize
  - Waveguide length
  - Number of crossings between waveguides
  - Number of bends
- Constraints:
  - Place all PSEs (and waveguides) inside chip area
  - No overlap

Valid and optimal layout

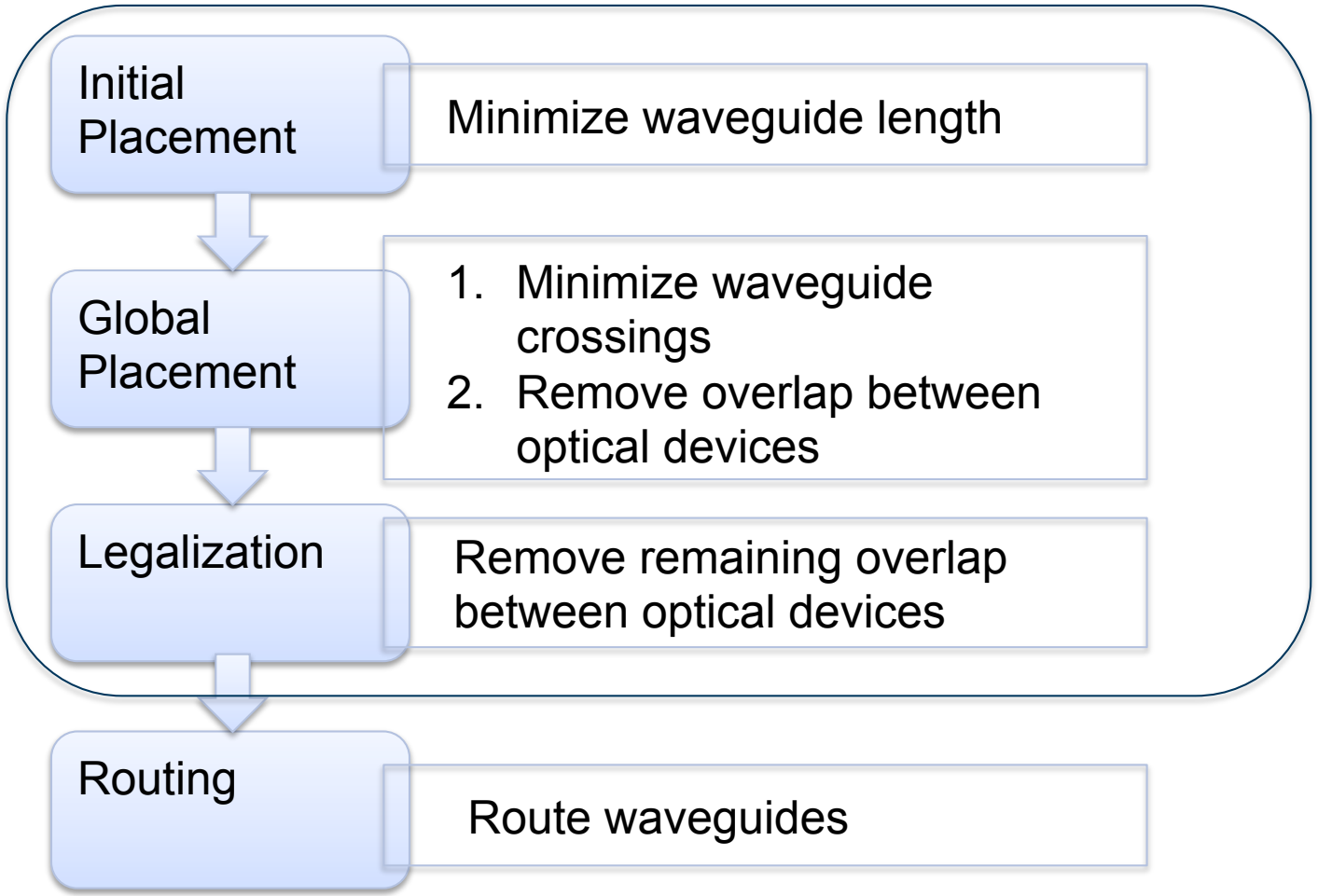




Placement and Routing Tools for ONoCs

	Place-ment	Routing	3D	Minimize Laser Power Consumption	Speed of Placement
Seo+ ISQED‘05	✓	✓	✗	✗	N/A
Minz+ TCPT‘07	✗	✓	✓	✗	✗
Ding+ DAC‘09	✗	✓	✓	✓	✗
Condrat+ TCAD‘14	✗	✓	✓	✓	✗
Boos+ ICCAD‘13	✓	✓	✓	✓	–
Our Approach	✓	✓	✓	✓	+

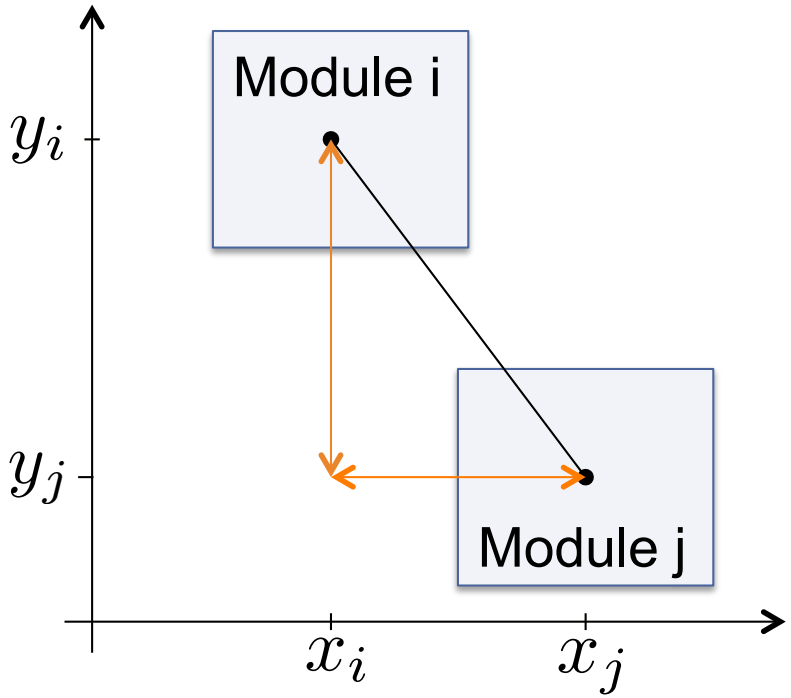
Our Approach



Initial Placement (1)

- Minimize **quadratic** length of nets

- $\tilde{L}(\mathbf{x}, \mathbf{y})$ = approximated waveguide length
- P = set of all paths
- N_p = set of all nets in path p



$$\tilde{L}(\mathbf{x}, \mathbf{y}) = \sum_{p \in P} \sum_{(i,j) \in N_p} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

Initial Placement (2)

$$\tilde{L}(\mathbf{x},\mathbf{y}) = \sum_{p\in P}\sum_{(i,j)\in N_p} \frac{\omega_{ij}}{2}(x_i - x_j)^2 + \frac{\omega_{ij}}{2}(y_i - y_j)^2$$

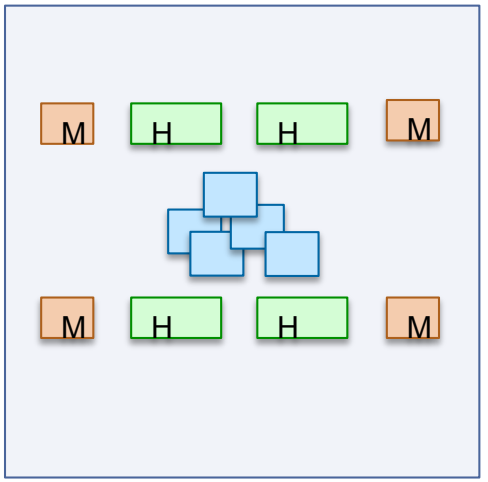
$$= \frac{1}{2}\mathbf{x}^T\mathbf{C_x}\mathbf{x} + \mathbf{x}^T\mathbf{d_x} + \frac{1}{2}\mathbf{y}^T\mathbf{C_y}\mathbf{y} + \mathbf{y}^T\mathbf{d_y}$$

- Minimize waveguide length

$$\nabla_x \tilde{L}(\mathbf{x},\mathbf{y}) = \mathbf{C_x}\mathbf{x} + \mathbf{d_x} = \mathbf{0} = F_x^{net}$$

$$\nabla_y \tilde{L}(\mathbf{x},\mathbf{y}) = \mathbf{C_y}\mathbf{y} + \mathbf{d_y} = \mathbf{0} = F_y^{net}$$

- Solve linear equation system by Conjugate Gradients method (CG)



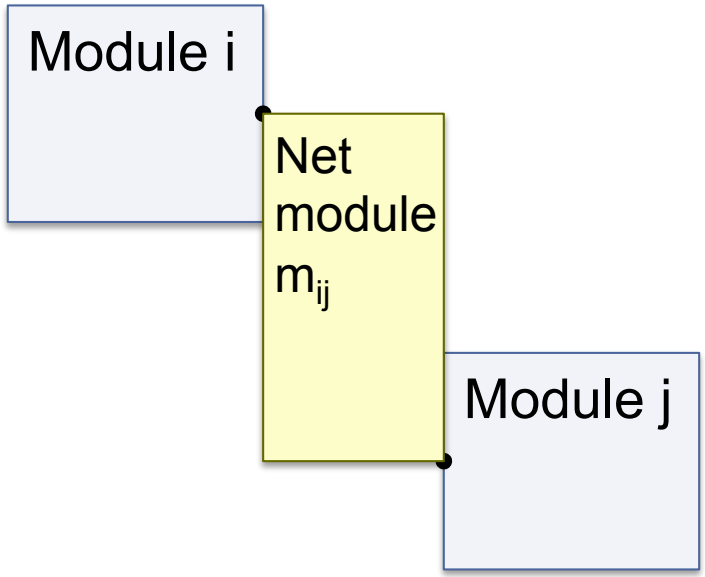
Global Placement

While net module overlap > 20%

$$\mathbf{F}^{net} + \mathbf{F}^{hold} + \mathbf{F}^{move,cross} = \mathbf{0}$$

While overlap between optical devices > 20%

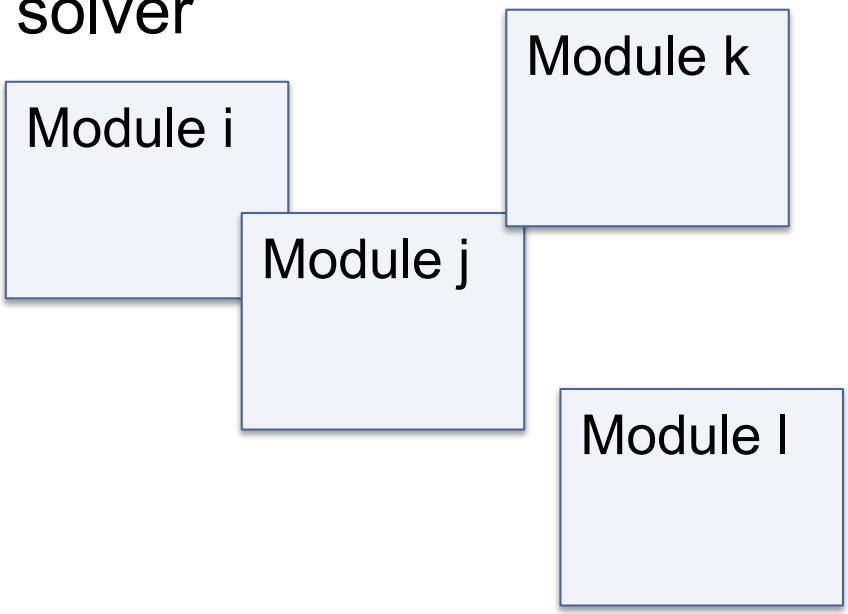
$$\mathbf{F}^{net} + \mathbf{F}^{hold} + \mathbf{F}^{move} = \mathbf{0}$$



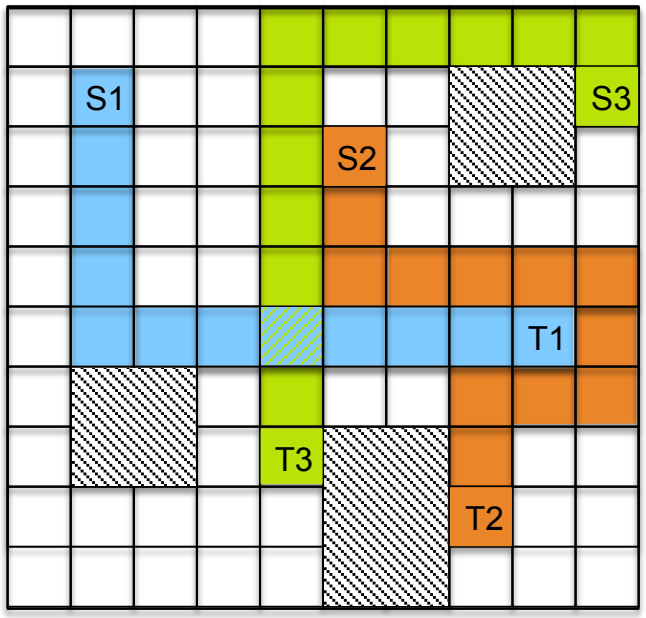
- Hold force $\mathbf{F}^{hold}$ compensates net force $\mathbf{F}^{net}$
- Move force $\mathbf{F}^{move}$ attracts optical devices to empty spaces
- Move force $\mathbf{F}^{move,cross}$ attracts net modules to empty spaces

Legalization and Routing

- Legalization: remove remaining overlap between optical devices by a quadratic problem solver

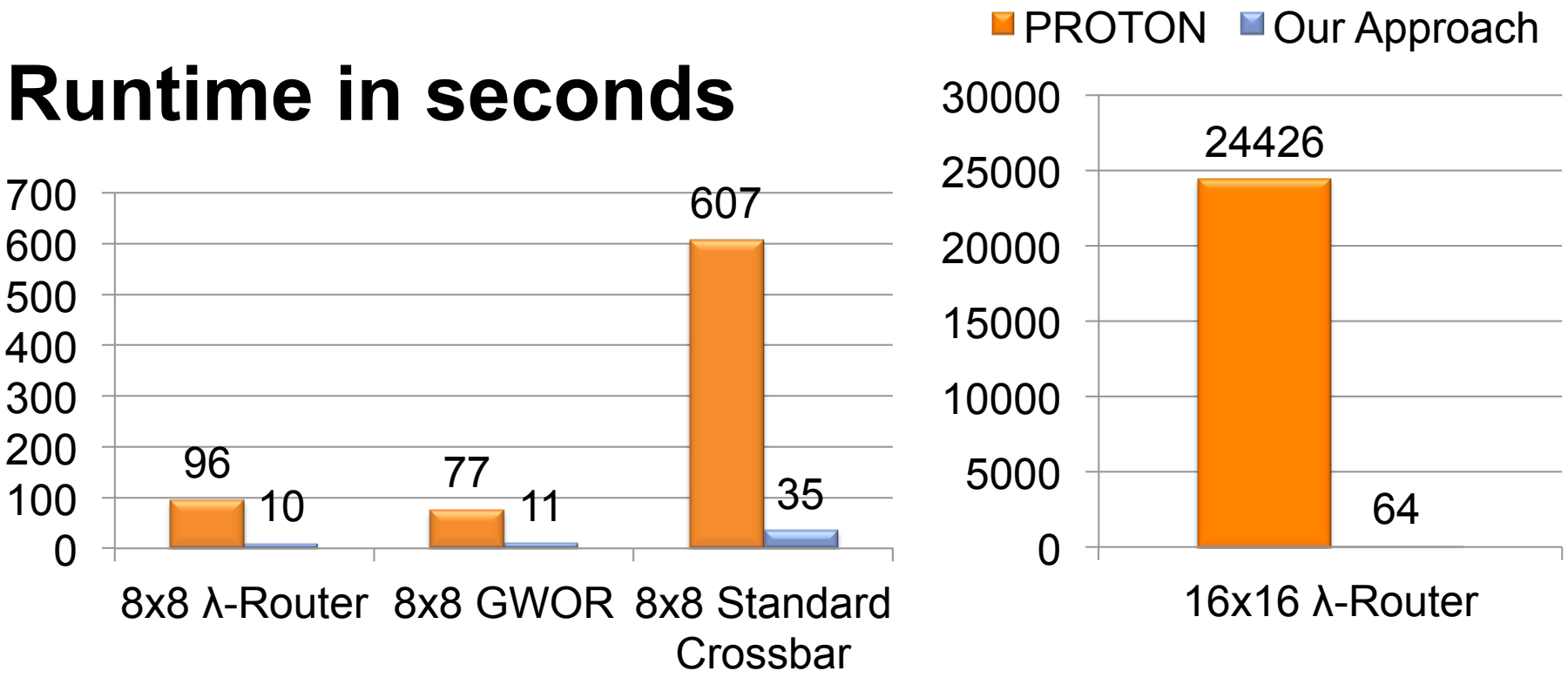


- Routing: Maze Router presented in Boos+ ICCAD‘13



Maximum Insertion Loss

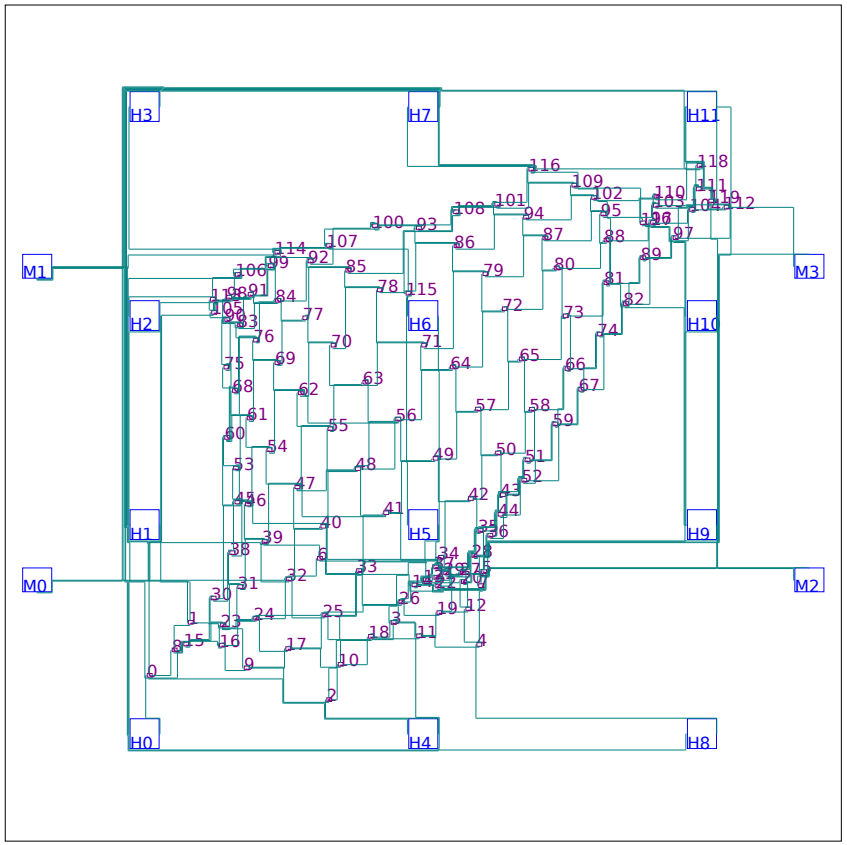
Runtime in seconds



	Number of PSEs	Number of nets
8x8 λ-Router	28	64
8x8 GWOR	24	56
8x8 Standard Crossbar	64	111
16x16 λ-Router	120	256

Resulting Layout of 16x16 λ-Router

PROTON [Boos+ ICCAD'13]



Our Approach

Conclusion

- First automatic force-directed placement of ONoCs
  - Minimize waveguide length during initial placement
  - Remove waveguide crossings and module overlap during global placement
- Comparison with PROTON [Boos+ ICCAD'13]
  - Maximum insertion loss decreased up to 48.9% for large topology
  - Runtime decreased up to 99.7% for large topology
- Future work
  - Improve routing algorithm