Temperature and Process Variation-Aware Wavelength Selection in Photonic NoCs

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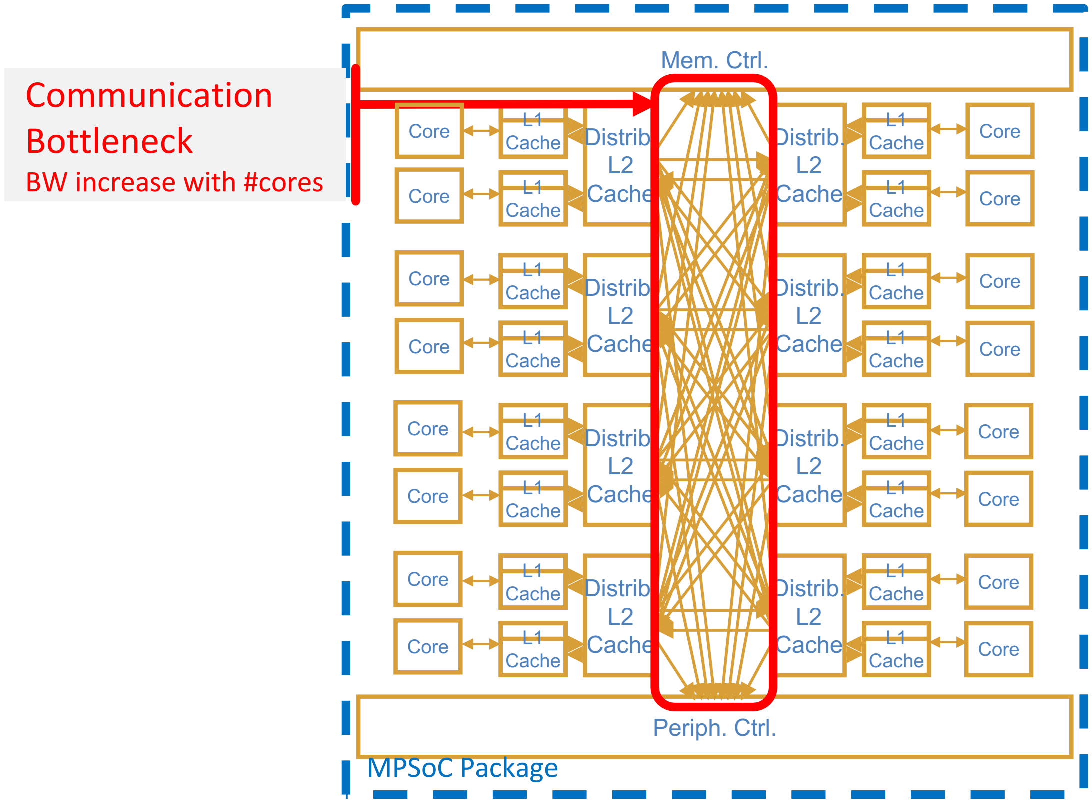
Communication bottleneck in manycore systems



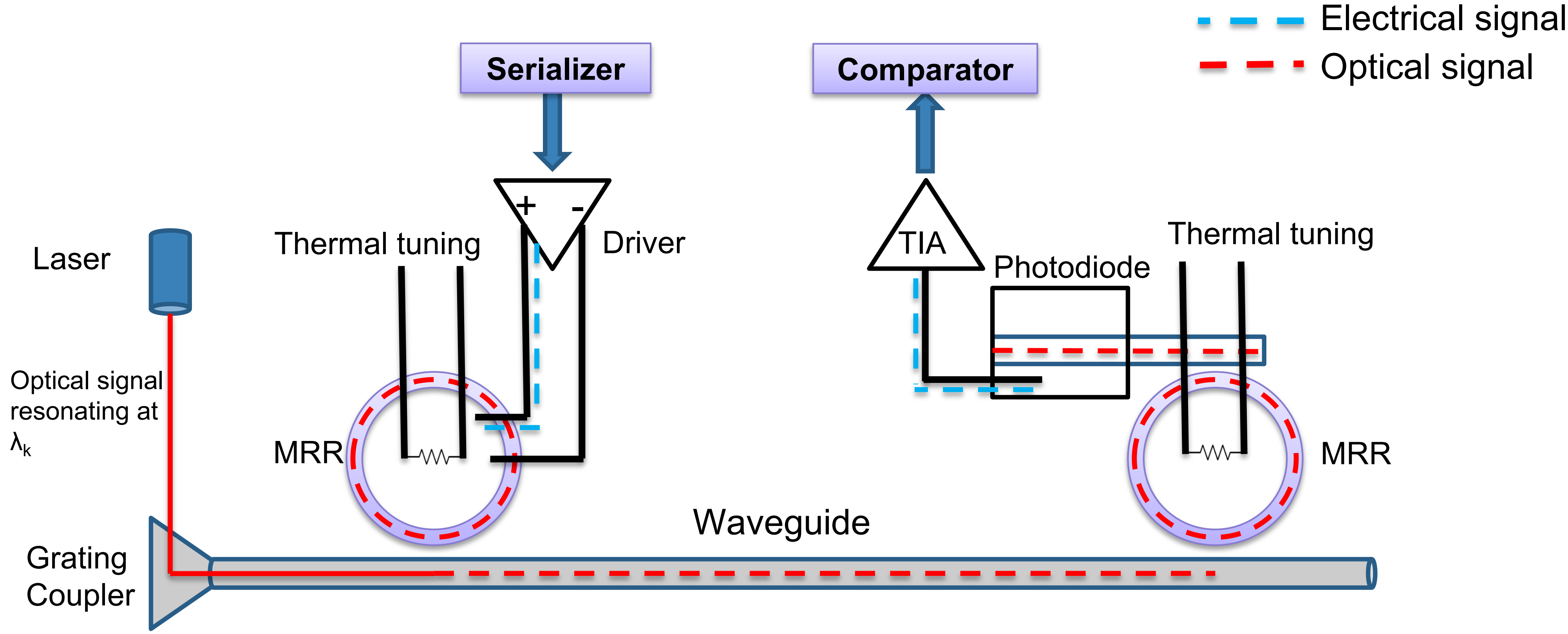
Electrical NoCs

- Constrained bandwidth
- High energy consumption of high-speed SerDes links
  → 20pJ/bit
- Long latencies

Photonic NoCs

- Wavelength-division multiplexing
  → Higher bandwidth
- Lower data-dependent power
  → 1.54 pJ/bit
- Lower latencies

Operation of a PNoC

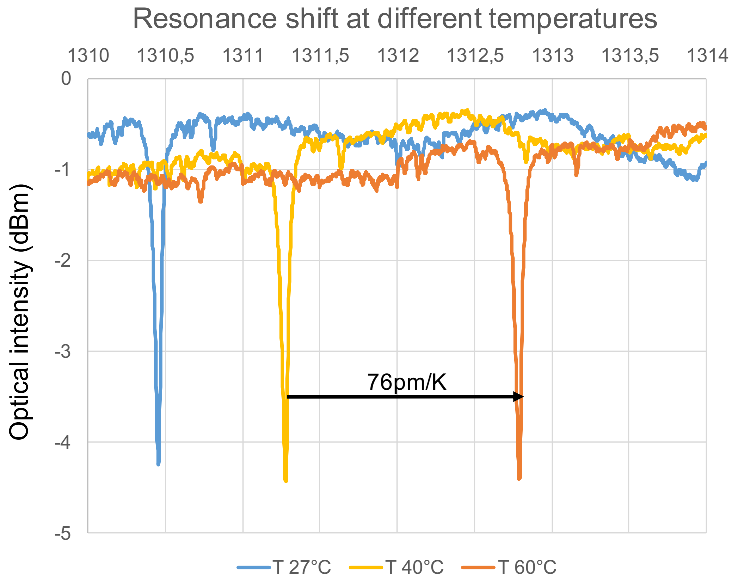


MRR ➔ Microring resonator
TIA ➔ Transinduction amplifier

Thermal and process variation sensitivity of MRRs

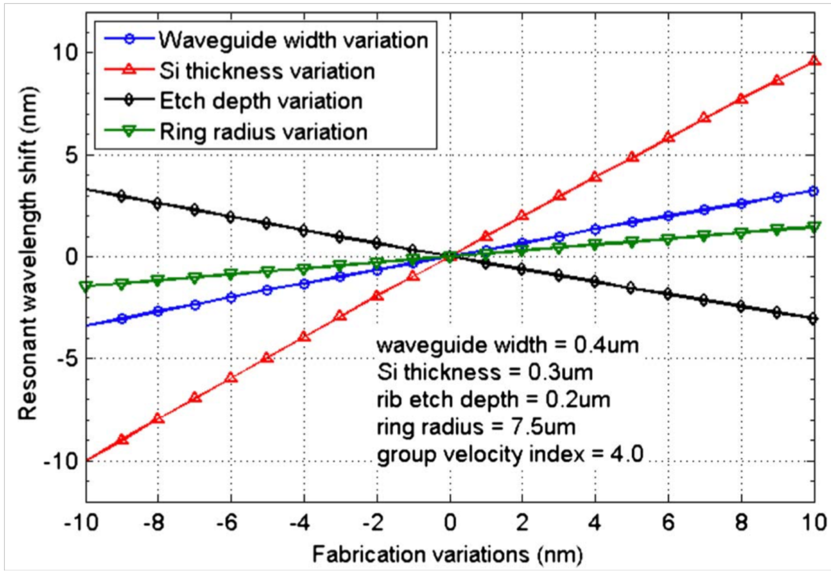
Thermal variation (TV) effect

Due to TV, refractive index of Si changes



Measured at CEA-Leti [Thonnart *et al*. ISSCC'18]

Process variation (PV) effect



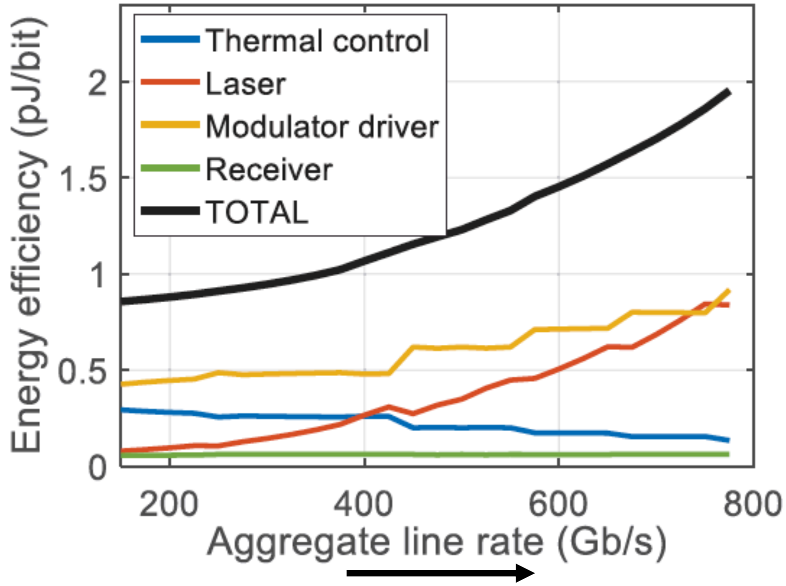
Krishnamoorthy *et al.*, IEEE Photonics Journal 2011

Δλ ~ 1nm/nm*thickness

PNoC power concerns

To achieve a goal of **50GFLOPs/W** for exascale computing, we need data movement energy to be **< 0.1pJ/bit**

PNoC power
→ Laser
→ EOE
→ Thermal tuning of MRRs



Number of activated laser wavelengths (λ_{act})

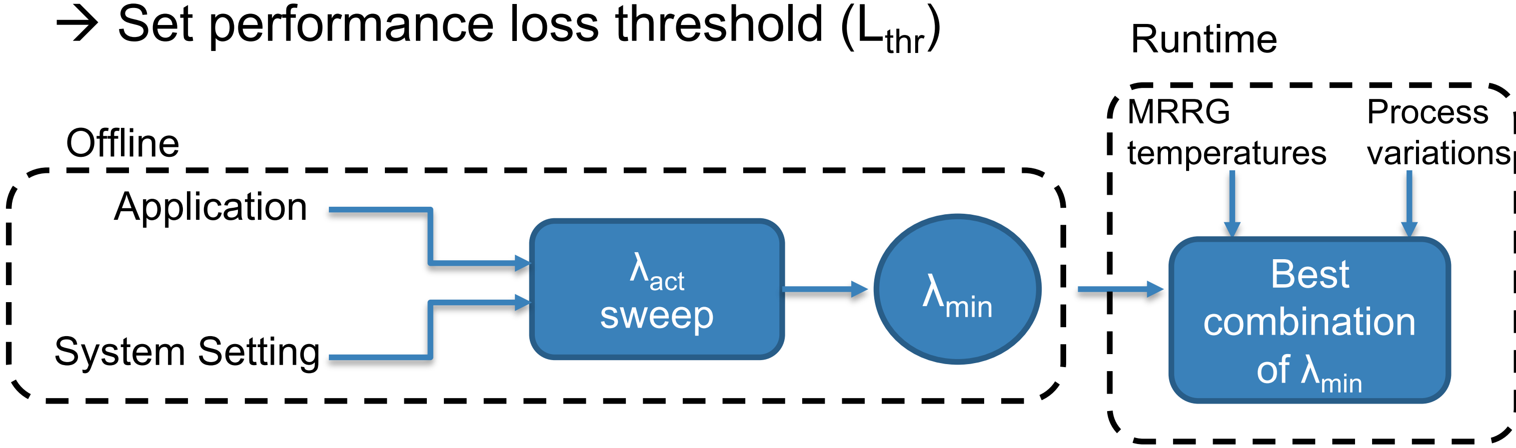
Bahadori *et al.* DATE'17

PNoC power increases with the number of activated laser wavelengths (λ_{act}) in the system

Minimize λ_{act}

Contribution of wavelength selection (WAVES)

- Identify and activate λ_{min} for an application which provides minimal loss in performance
  → Set performance loss threshold (L_{thr})

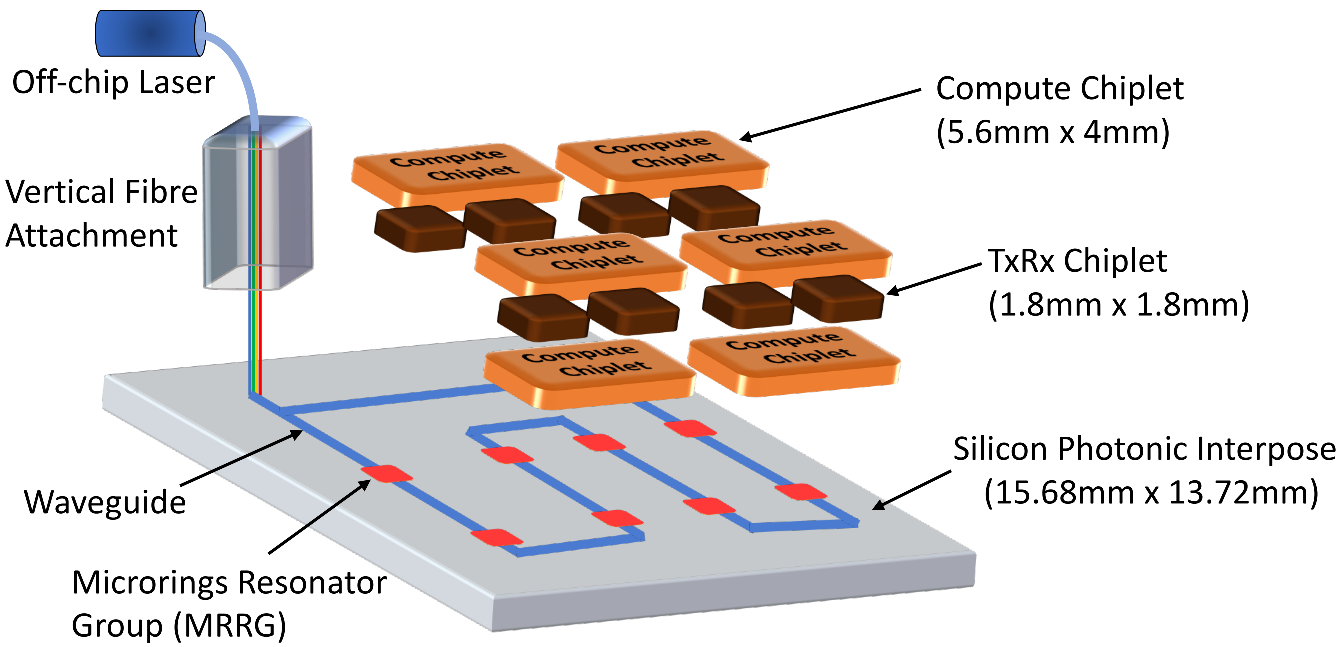


+ Minimal Storage (200KB)
+ Low latency (~5ns)

- Cross-layer simulation framework to model the system performance and PNoC power (laser, electronics and heating)
  → We explore the optimizations of PNoC power arising from the device-level MRR locking under different system-level constraints

POPSTAR: 2.5D manycore system with PNoCs

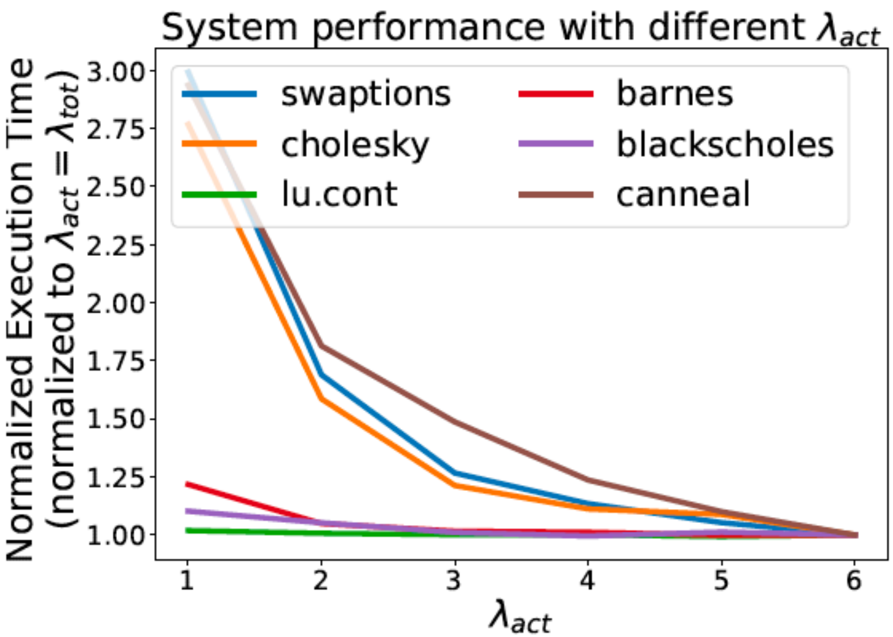
POPSTAR → Processors On Photonic Silicon inTerposer ARchitecture

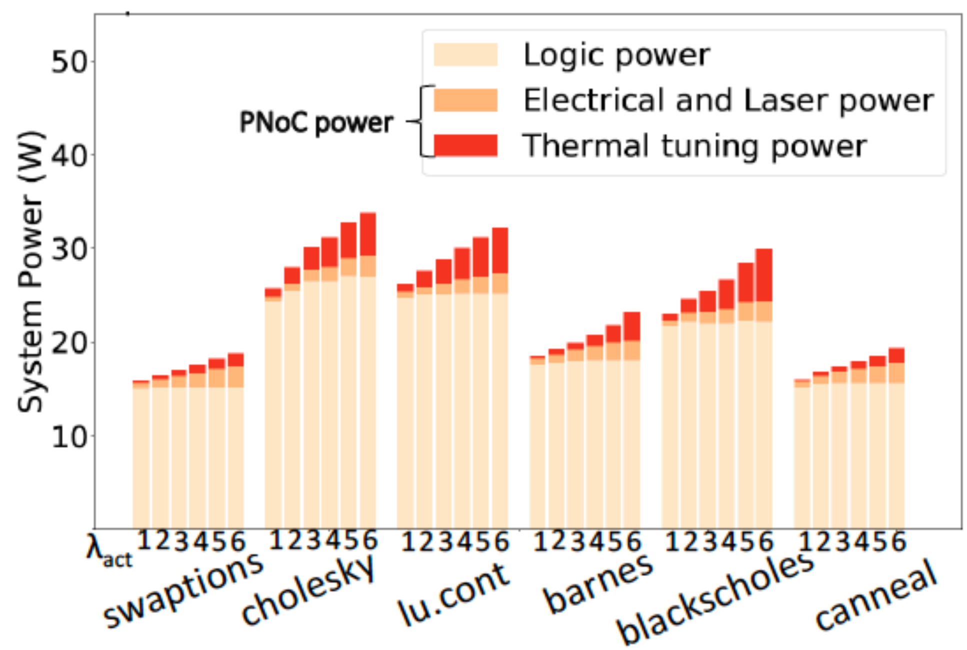


- 96-core 2.5D manycore system
  → 16 cores per chiplet
  → *TSARLET* chiplet [Guthmuller *et al*. ESSCC'18]
  → IA32 core from Intel SCC [Howard et al. ISSCC'10]

- Off-chip laser emits up to 6 wavelengths
  → Data rate of 12Gbps
  → Peak aggregate bandwidth of 576Gbps

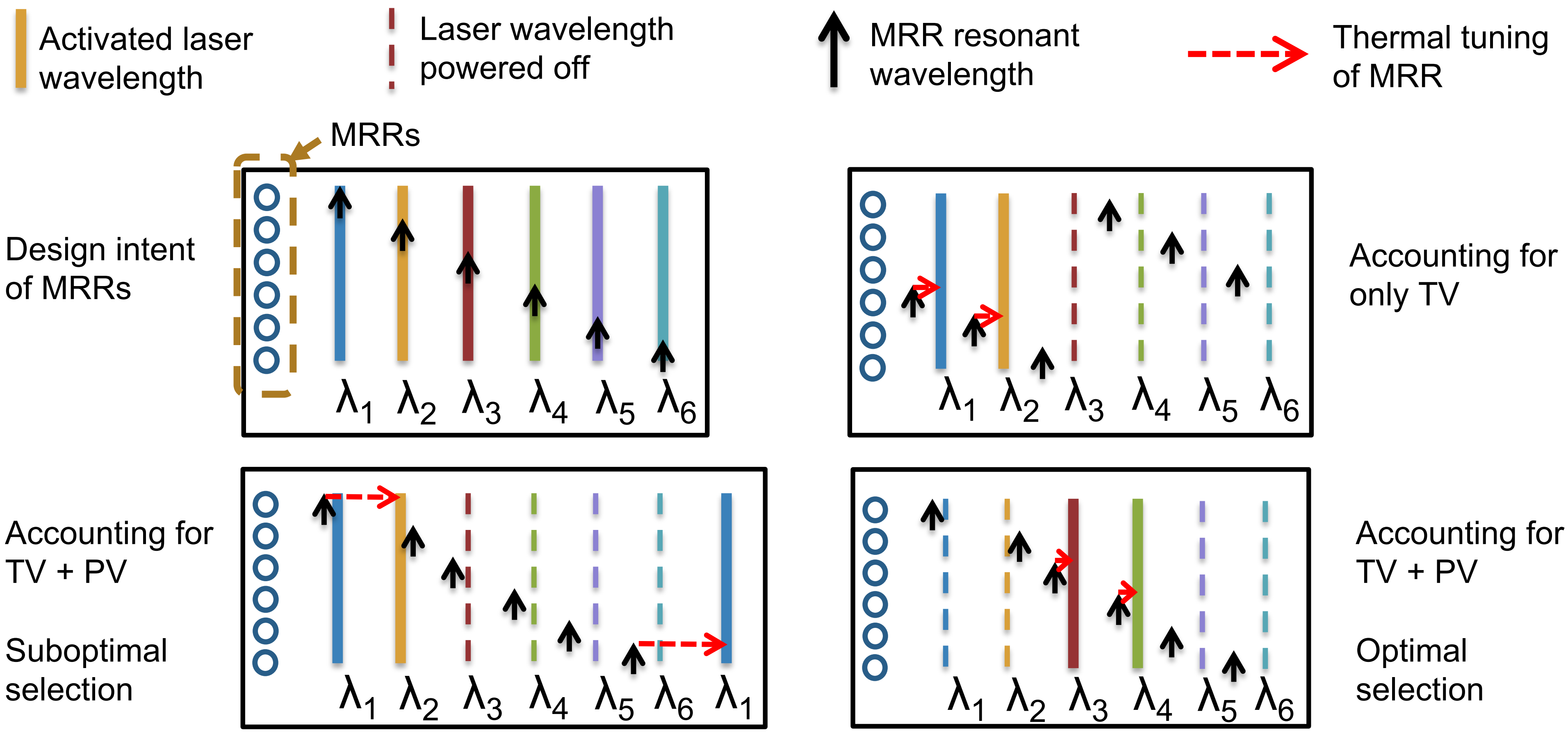
Motivation for wavelength selection (WAVES)



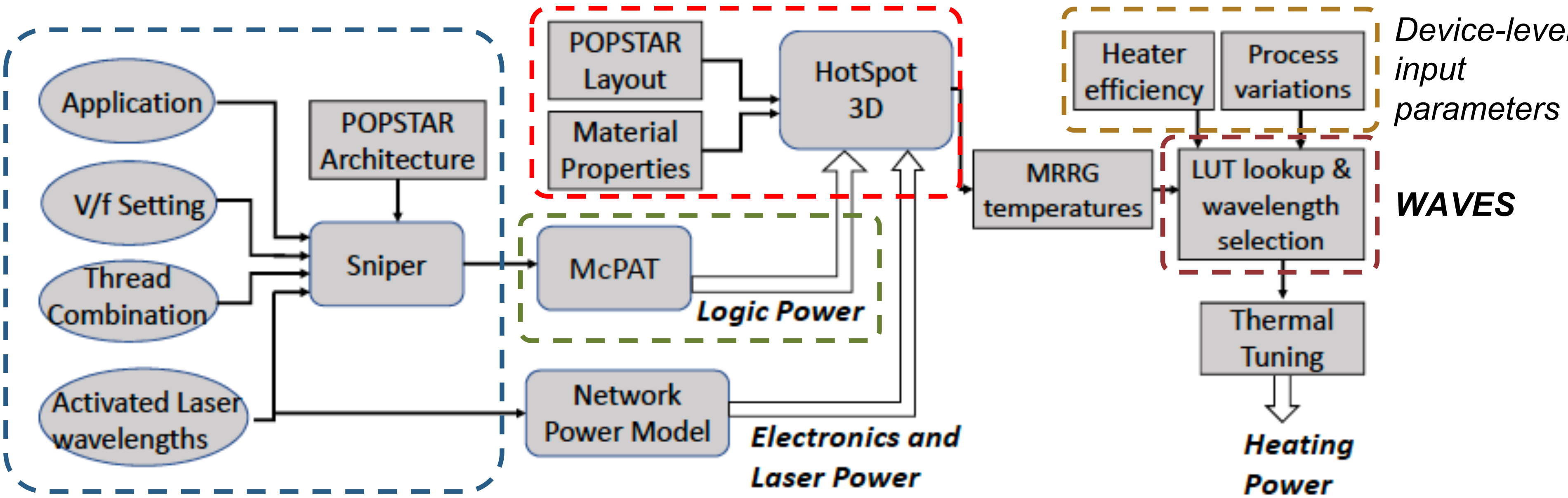


- PNoC power increases with number of activated laser wavelengths (λ_{act})
- System performance saturates at a $\lambda_{min} < \lambda_{tot}$, which is dependent on application's bandwidth requirement

Accounting for thermal and process variations



Simulation framework

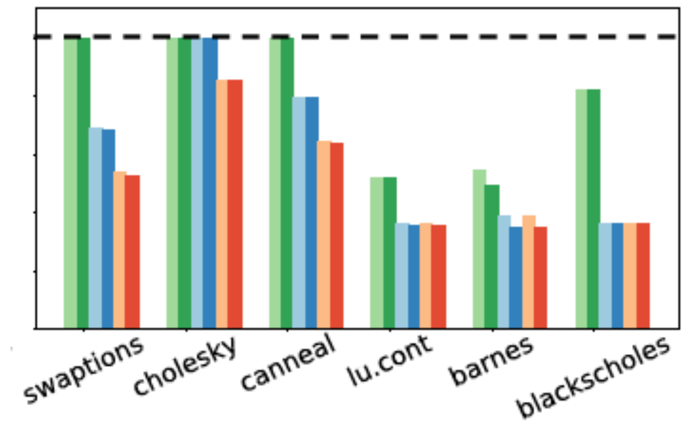


Benchmarks

- **PARSEC:** swaptions, canneal, blackscholes
- **SPLASH-2:** cholesky, barnes, lu.cont

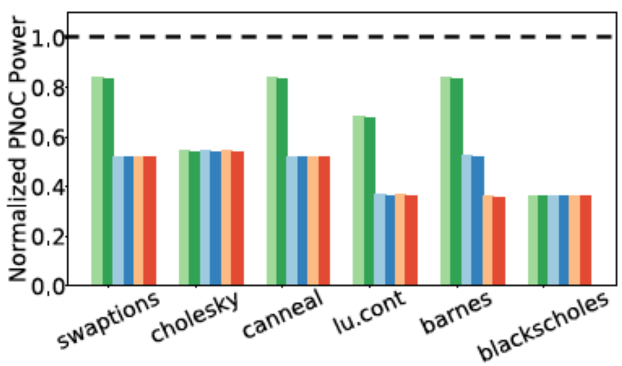
Each application executed for 10B instructions in the ROI

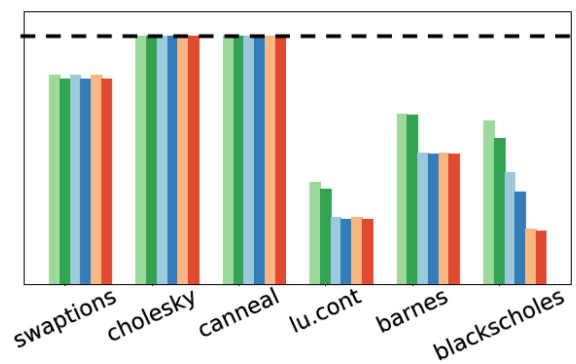
Experimental results



48 threads
50% utilization

24 threads
25% utilization





96 threads
100% utilization

Average power savings for different configurations

L_{thr} : Performance loss threshold set compared to $\lambda_{act}=\lambda_{tot}$

Configuration	Setting	L_{thr} 1%	5%	10%
Applications	*high_comm*	8%	21%	26%
	low_comm	38%	56%	61%
DVFS settings	*high_perf*	19%	34%	39%
	low_perf	26%	41%	45%
Thread counts	24 threads	28%	48%	54%
	48 threads	18%	37%	45%
	72 threads	26%	34%	36%
	96 threads	18%	31%	33%
Average		**23%**	**38%**	**42%**

Applications: Increased power savings

DVFS settings: Increased power savings

Thread counts: Power savings decreases

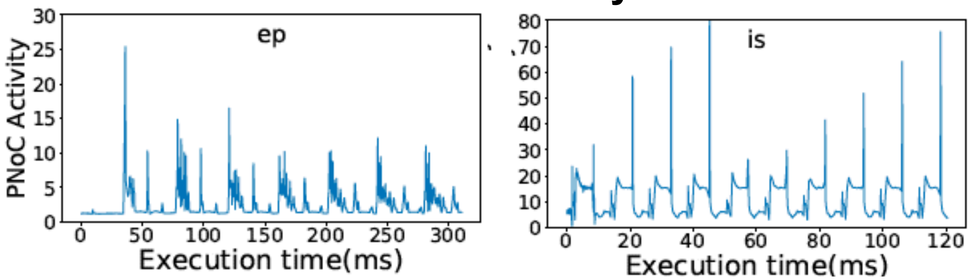
Conclusion and current directions

➢ WAVES achieves 23% (resp. 38%, 42%) average PNoC power savings with only 1% (resp. 5%, 10%) system performance loss.

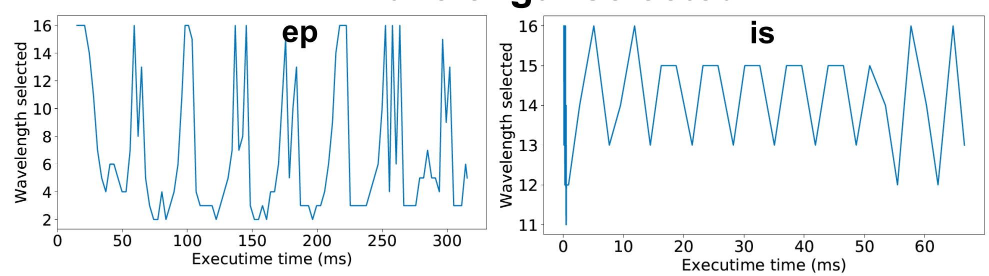
Application's BW needs are highly dynamic

- Dynamic wavelength selection policy
- Proactively activate λ_{min} for each interval based on the PNoC activity

PNoC activity



Wavelength selected



The full version of this paper will appear in *Design, Automation and Test in Europe (DATE)*, Mar. 2019