OWN: OPTICAL AND WIRELESS NETWORK-ON-CHIP FOR KILO-CORE ARCHITECTURES

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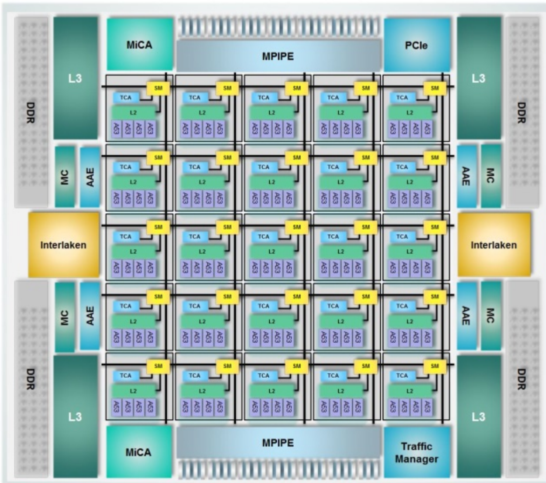
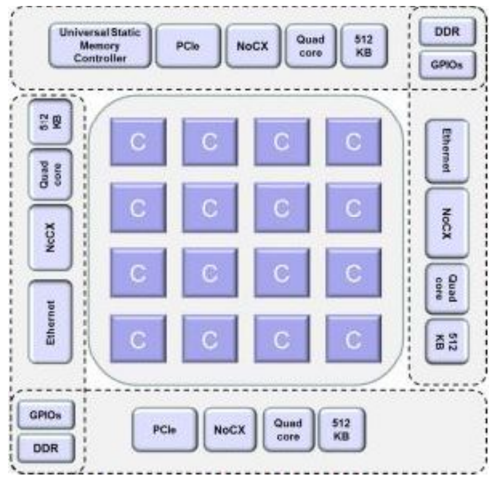
Talk Outline

- Motivation & Background
- OWN: Architecture & Communication
- Performance Analysis
- Conclusions & Future Work

Multi-cores & Network-on-Chips



TILE-Mx100[1]



MPPA-256 Kalray[2]

GF100 512-Core (Nvidia)[3]

- With increasing multiple number of cores, communication-centric design paradigm (Network-on-Chips) is facing challenges due to:
  - Higher power dissipation: long metallic wires
  - Area overhead: more router components
  - Increased Latency: Complex multi-hop routing

=> Potential solutions: Emerging technologies such as **optics, wireless**

[1]http://www.tilera.com/products/?ezchip=585&spage=686

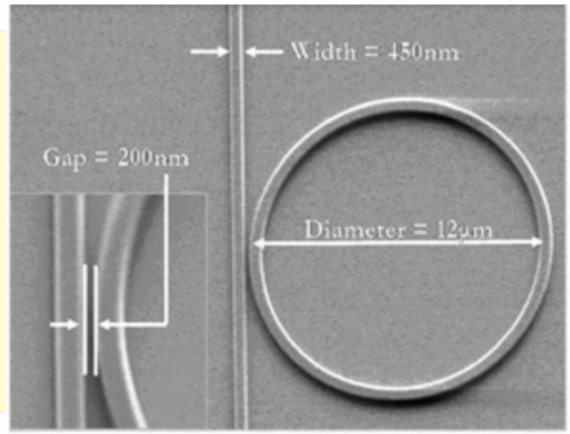
[2]http://www.kalrayinc.com/kalray/products/

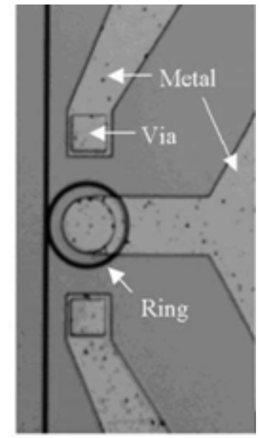
[3]http://www.nvidia.com/object/IO_86775.html

Optical Network-on-Chip

Optical NoC offers several advantages:

- Low power (~7.9 fJ/bit)
- Low latency (~500ps)
- High Bandwidth (~40 Gbps)
- CMOS compatibility





1. Lin Xu; Wenjia Zhang; Qi Li; Chan, J.; Lira, H.L.R.; Lipson, M.; Bergman, K., "40-Gb/s DPSK Data Transmission Through a Silicon Microring Switch," *Photonics Technology Letters, IEEE* , vol.24, no.6, pp.473,475, March15, 2012
2. Sasikanth Manipatruni, Kyle Preston, Long Chen, and Michal Lipson, "Ultra-low voltage, ultra-small mode volume silicon microring modulator," Opt. Express 18, 18235-18242 (2010)
3. J. Cunningham, R. Ho, X. Zheng, J. Lexau, H. Thacker, J. Yao, Y. Luo, G. Li, I. Shubin, F. Liu *et al*., "Overview of short-reach optical interconnects: from vcsels to silicon nanophotonics."
4. Xia, Fengnian, Lidija Sekaric, and Yurii Vlasov. "Ultracompact optical buffers on a silicon chip." *Nature photonics* 1.1 (2007): 65-71.

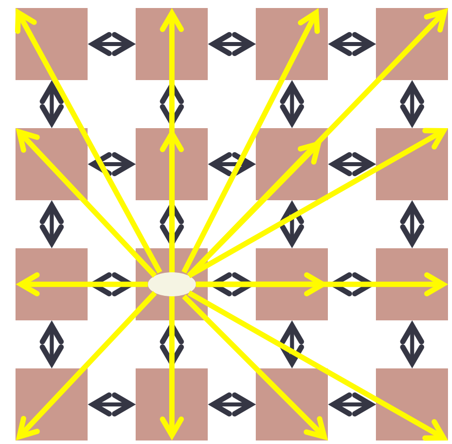
Disadvantages of optical NoC:

- Optical-only crossbar is not scalable for large core networks
- Multi-hop networks with smaller crossbar have increased latency for large core networks

Crossbar	64 x 64	1024 x 1024
Modulator	448	7168
Waveguide	7	112
Photodetector	~28224	~7.3 M
Insertion Loss	~11 dB/WL	~32 dB/WL

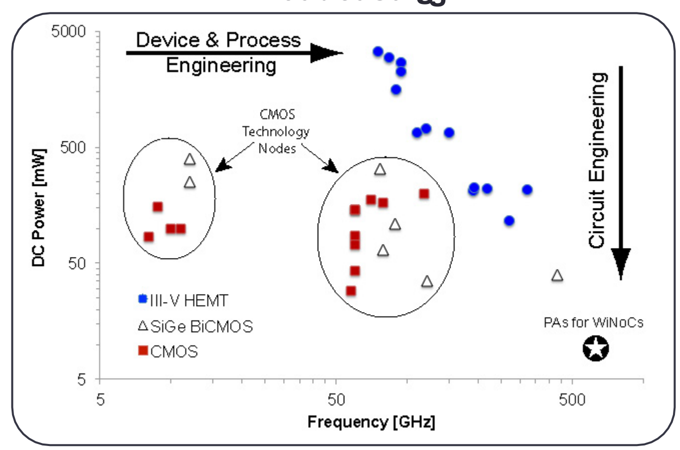
Wireless Network-on-Chip

- **Wireless offers several advantages:**
  - CMOS compatibility
  - Omnidirectional communication without wires using multicasting and broadcasting
  - Bandwidth extension using Frequency Division Multiplexing (FDM), Time Division Multiplexing (TDM), Space Division Multiplexing (SDM)



Multicasting / **Broadcasting**

- **Disadvantages of Wireless :**
  - High transceiver area and energy/bit
  - Low wireless bandwidth at 60 GHz center frequency for CMOS technology
  - Latency due to resource sharing

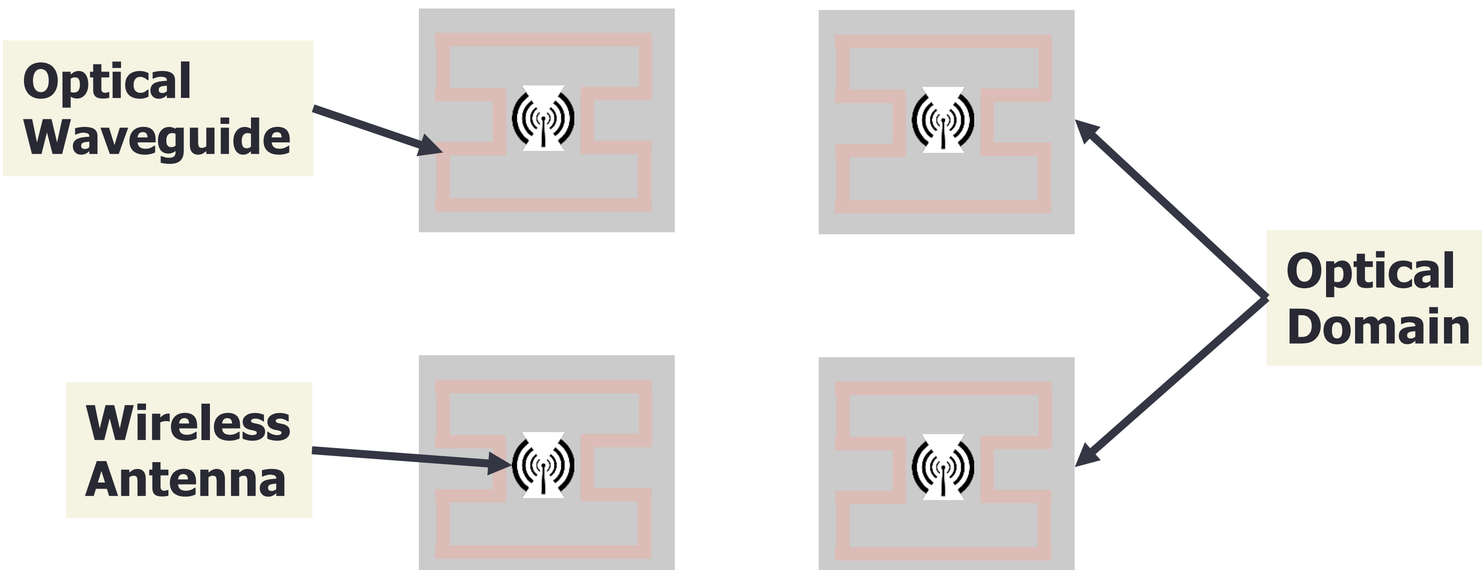


RF-CMOS transceiver trend for WiNoC[1]

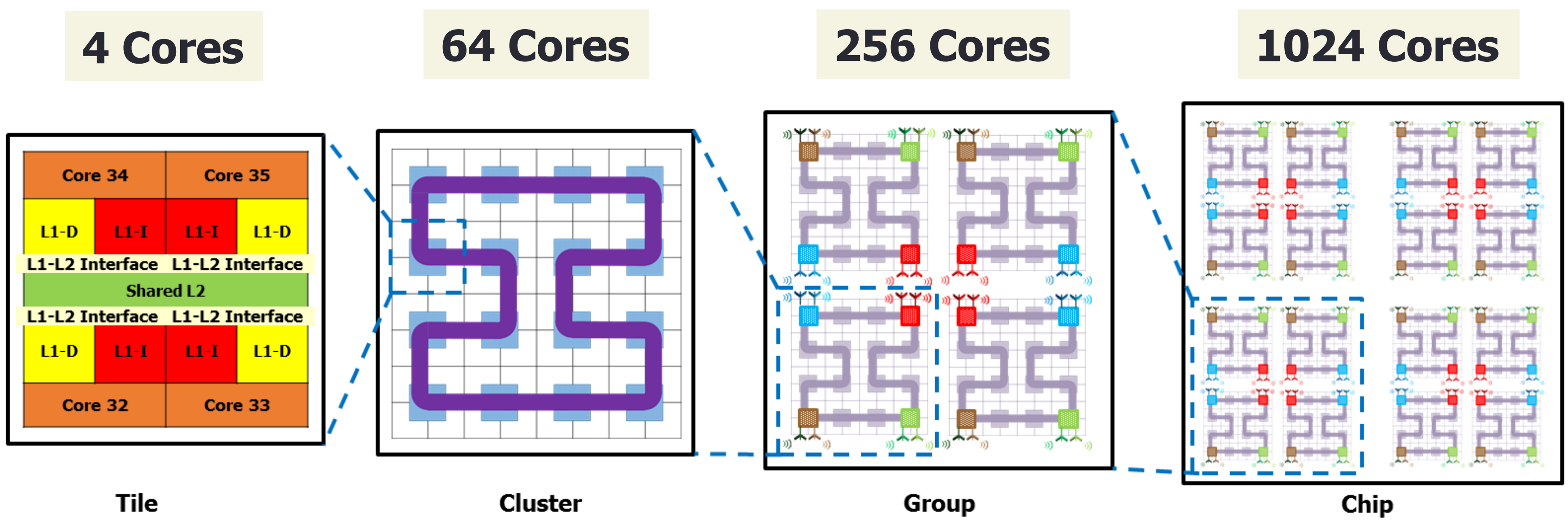
1. D. DiTomaso, A. Kodi, D. Matolak, S. Kaya, S. Laha, and W. Rayess, "Energy-efficient adaptive wireless nocs architecture," in *Networks on Chip (NoCS), 2013 Seventh IEEE/ACM International Symposium on*. IEEE, 2013, pp. 1–8.

Optical & Wireless NoC: OWN

- OWN combines the benefits of photonics and wireless to overcome the disadvantages of each technology
  - Smaller optical crossbar to provide one hop communication and reduce area and power overhead
  - Connect the optical domains via wireless to facilitate one hop communication between the domains

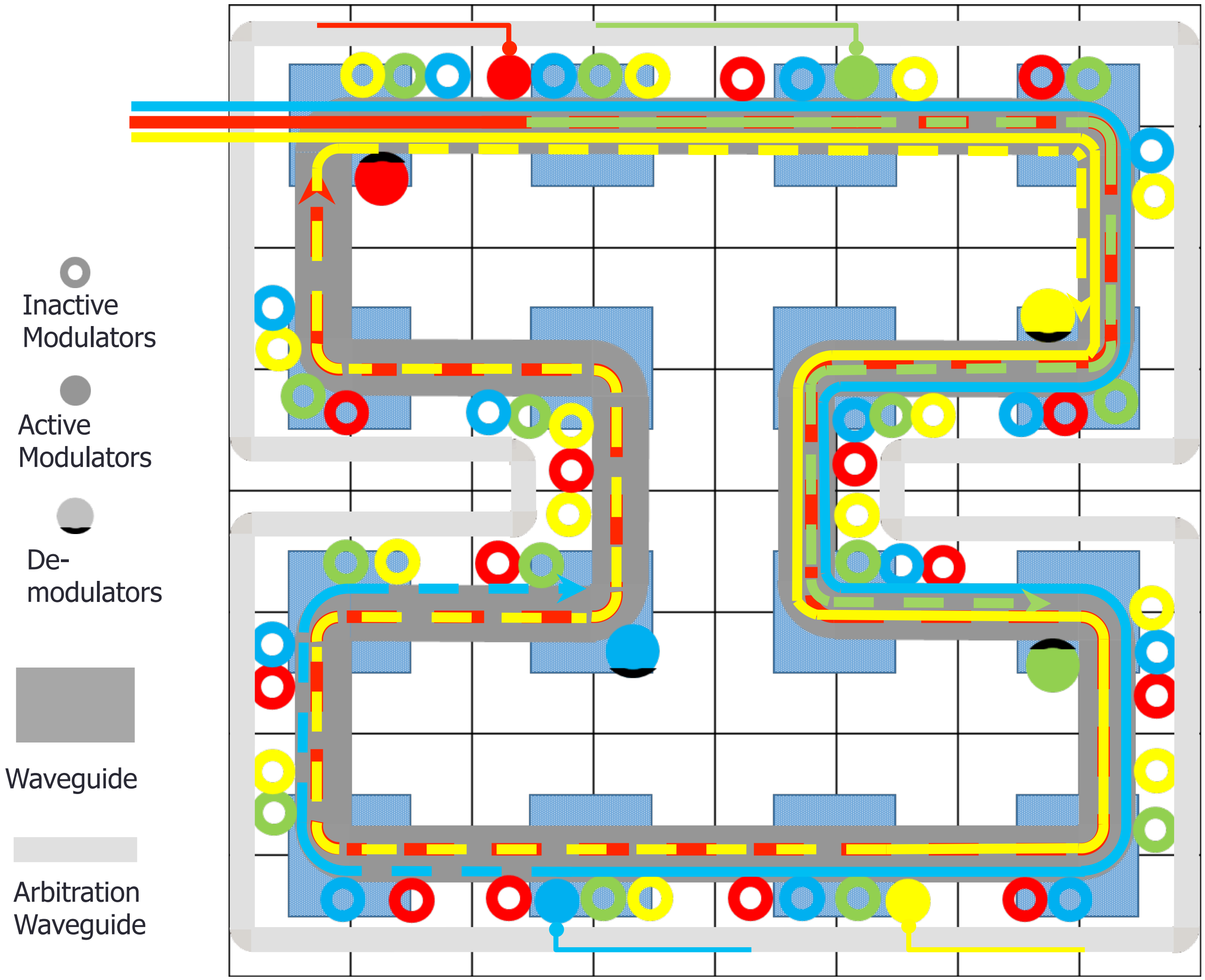


OWN Architecture & Communication (1/4)



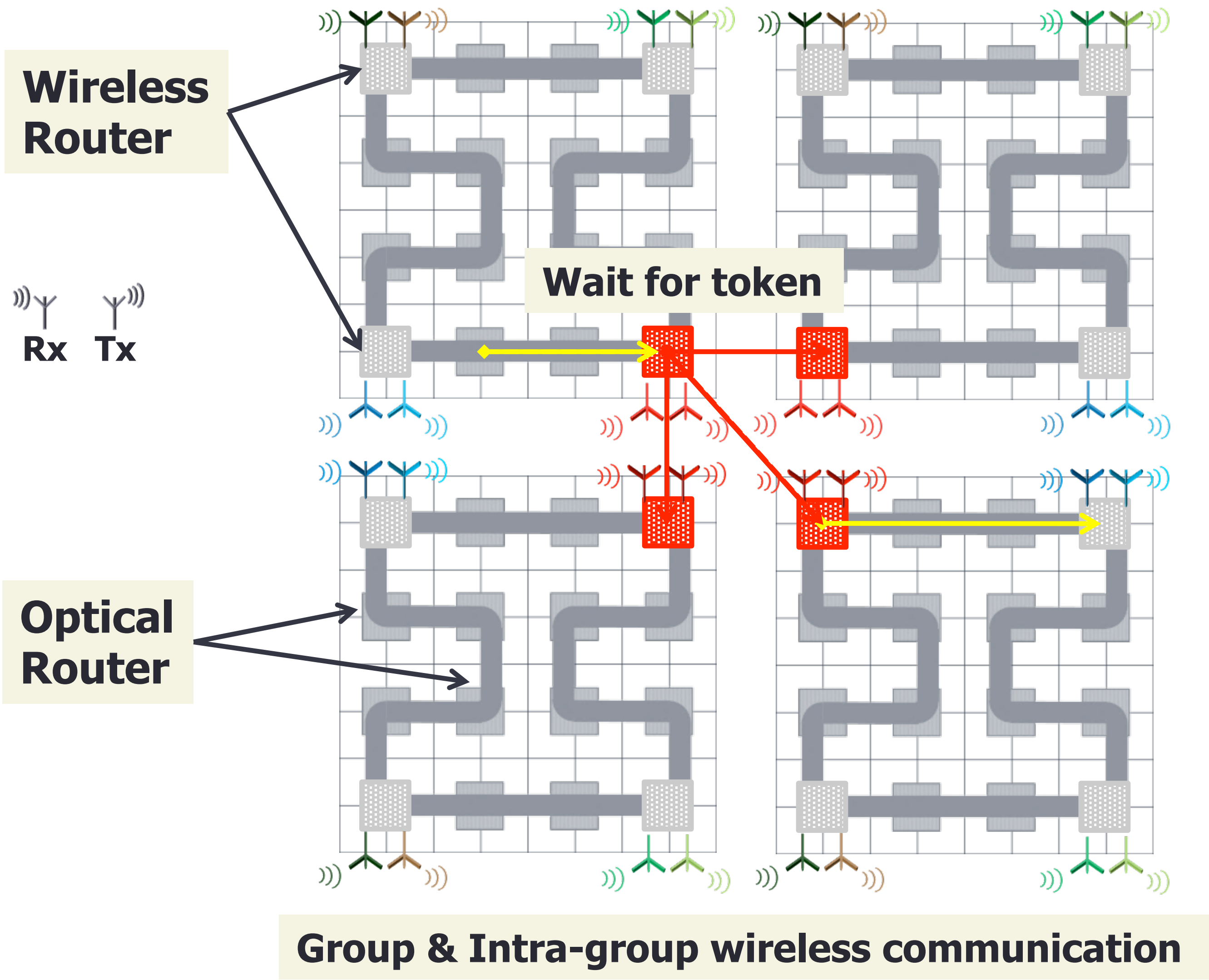
A *Tile* consists of 4 Cores => 16 Tiles form a *Cluster* => 4 Clusters create a *Group* => 4 Groups are on the *Chip*

OWN Architecture & Communication (2/4)

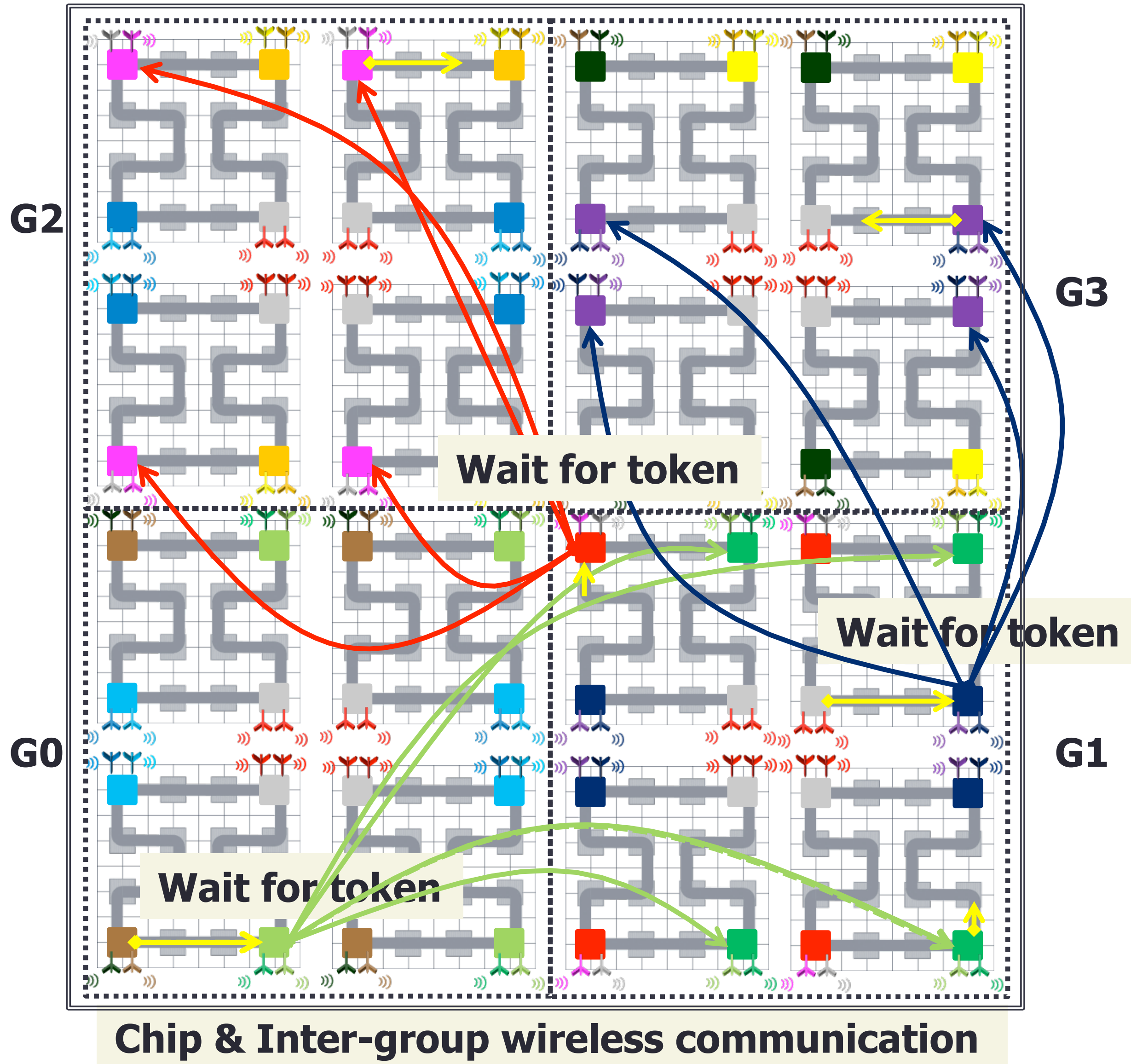


Cluster & Intra-cluster optical communication

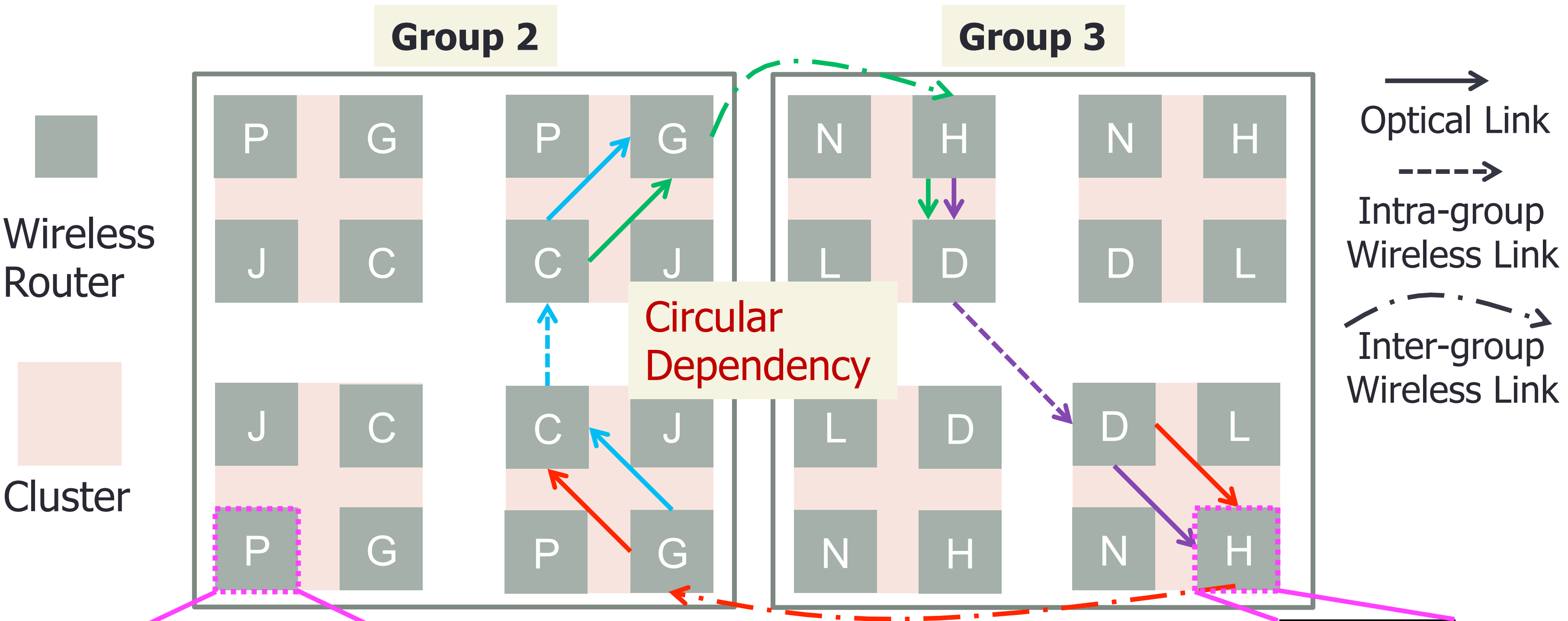
OWN Architecture & Communication (3/4)



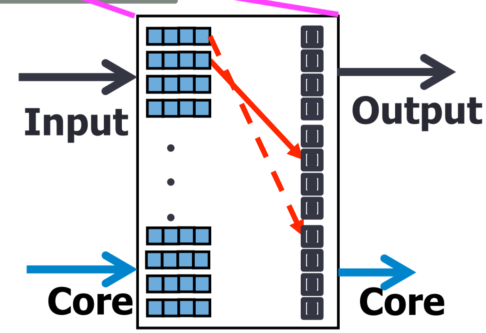
OWN Architecture & Communication (4/4)



OWN Deadlocks & Solution



- **VC0 = Intra-cluster & Intra-group**
- **VC1 = Inter-group horizontal**
- **VC2 = Inter-group vertical**
- **VC3 = Inter-group diagonal**



Solution => VC allocation based on packet types which requires 4 VCs per port

Performance Analysis

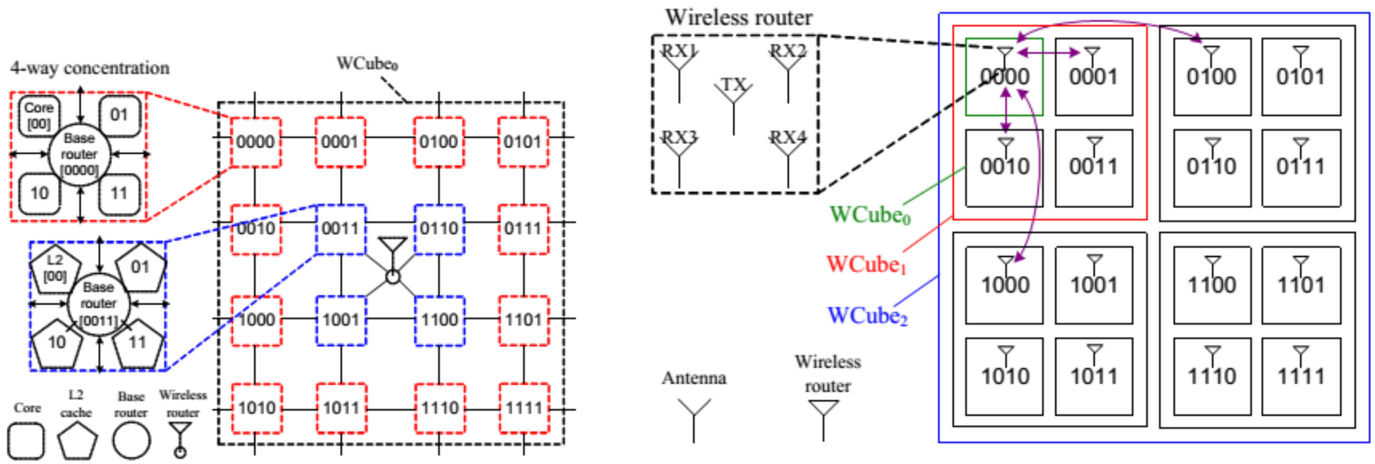
- Architectures: OWN, Cmesh (wired only), Wcube (hybrid wireless) and ATAC (hybrid optical)
- Number of cores: 1024
- Synthetic Benchmarks: Uniform (UN), Bit-Reversal (BR), Complement (COMP), Matrix Transpose (MT), Perfect Shuffle (PS), and Neighbor (NBR)
- Network Simulation: Optisim*
- Area and Power Analysis
  - Dsent# to calculate wire link and router area and power at bulk 45nm LVT
  - Optical link area and power (waveguide, micro-ring resonators, laser power)
  - Wireless transceiver area is 0.62 mm^2 and energy 1pJ/bit$

* A. Kodi and A. Louri, "A system simulation methodology of optical interconnects for high-performance computing systems," J. Opt. Netw, vol. 6, no. 12, pp. 1282–1300, 2007

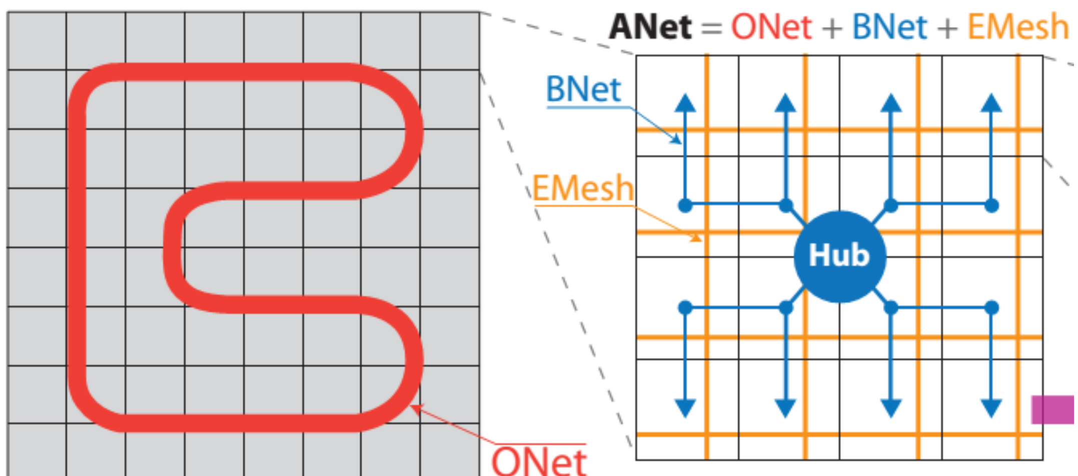
C. Sun, C.-H. Chen, G. Kurian, L. Wei, J. Miller, A. Agarwal, L.-S. Peh, and V. Stojanovic, "Dsent-a tool connecting emerging photonics with electronics for opto-electronic networks-on-chip modeling," in Networks on Chip (NoCS), 2012 Sixth IEEE/ACM International Symposium on. IEEE, 2012, pp. 201–210

$ D. DiTomaso, A. Kodi, D. Matolak, S. Kaya, S. Laha, and W. Rayess, "Energy-efficient adaptive wireless nocs architecture," in *Networks on Chip (NoCS), 2013 Seventh IEEE/ACM International Symposium on*. IEEE, 2013, pp. 1–8.

Related Work



Wcube[MobiCom'09]

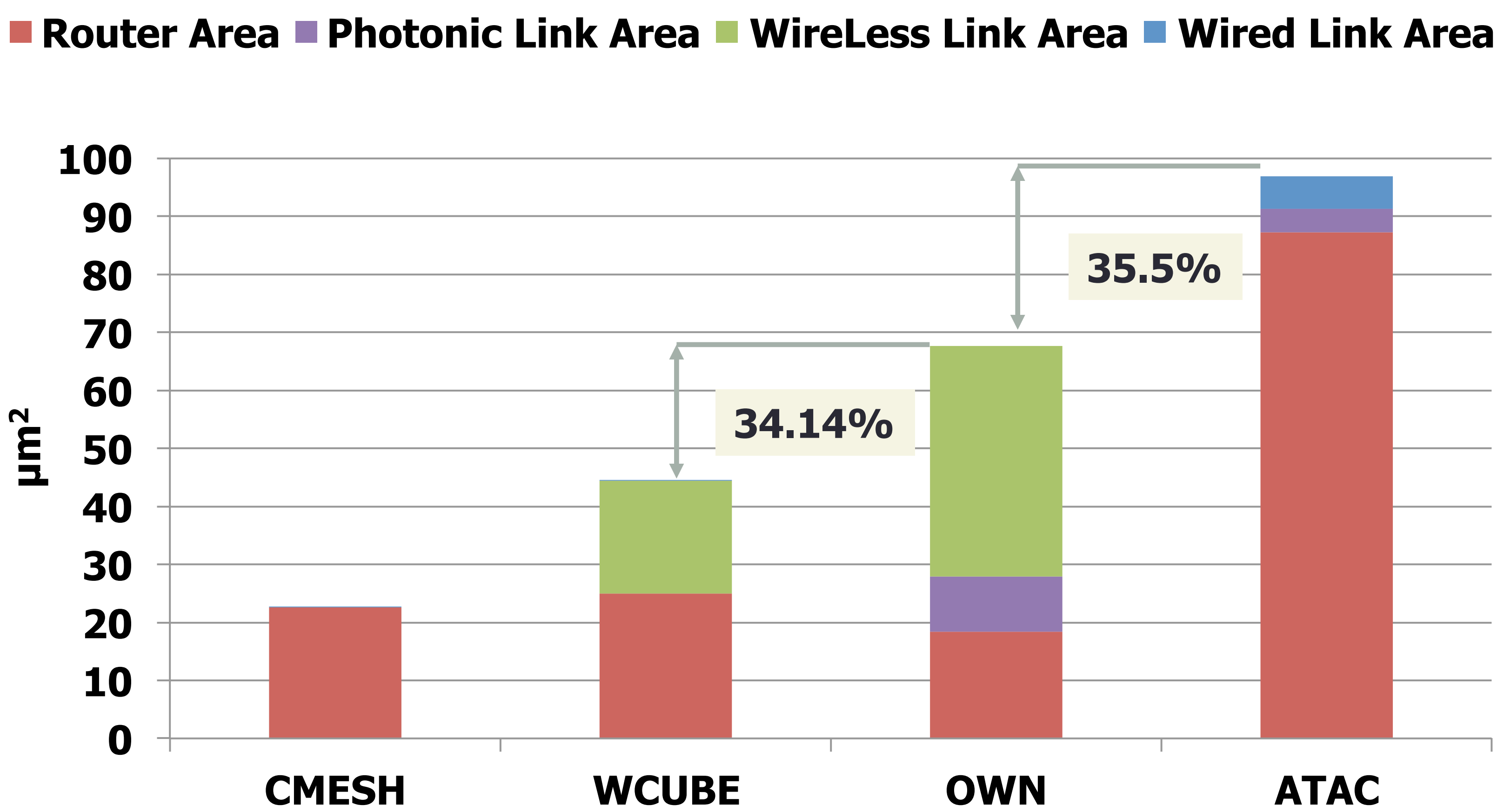


(a) 64 Optically-Connected Clusters

(b) Electrical In-Hub Networks Connecting 16 Cores

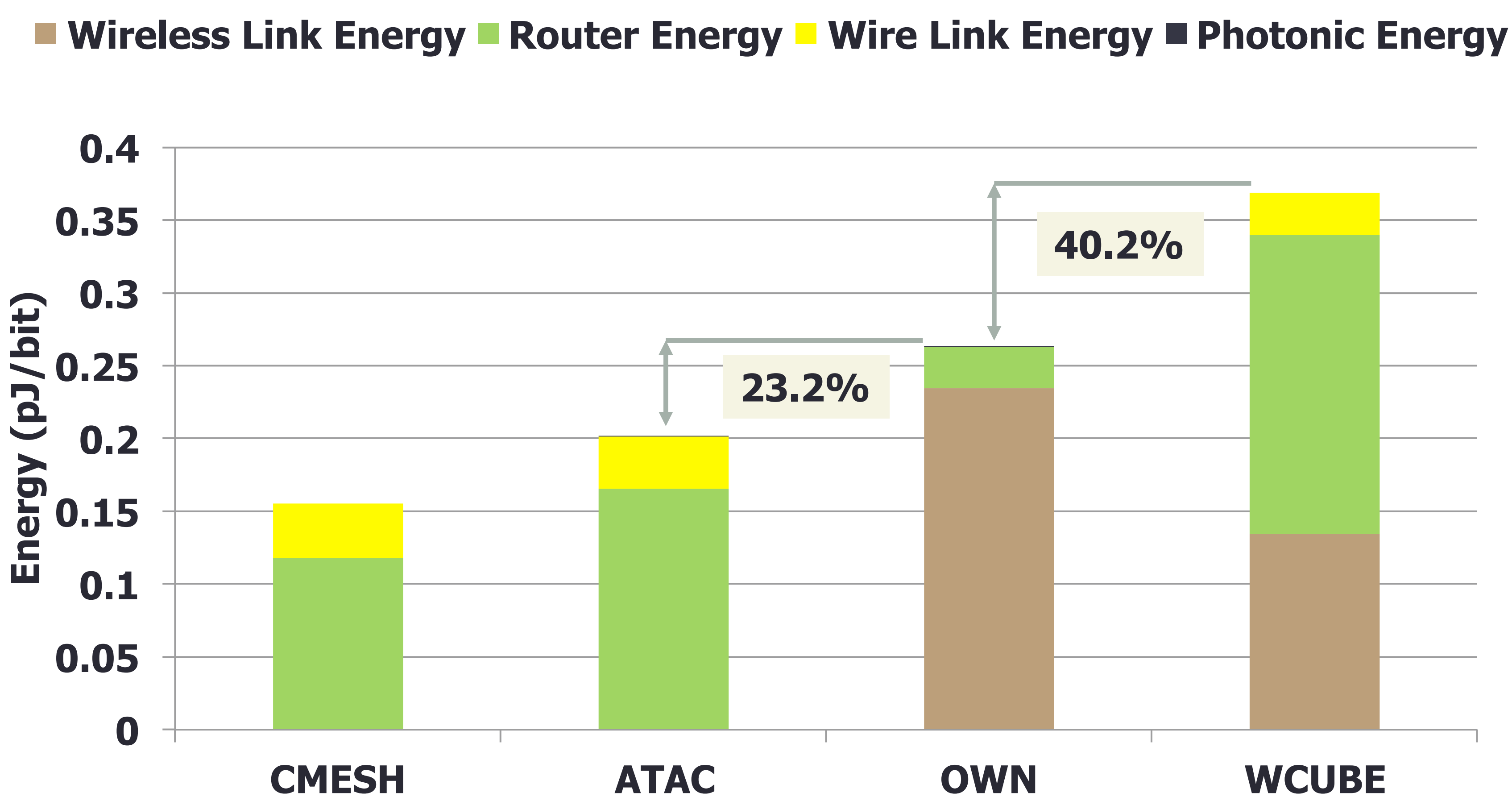
ATAC[PACT'10]

Area



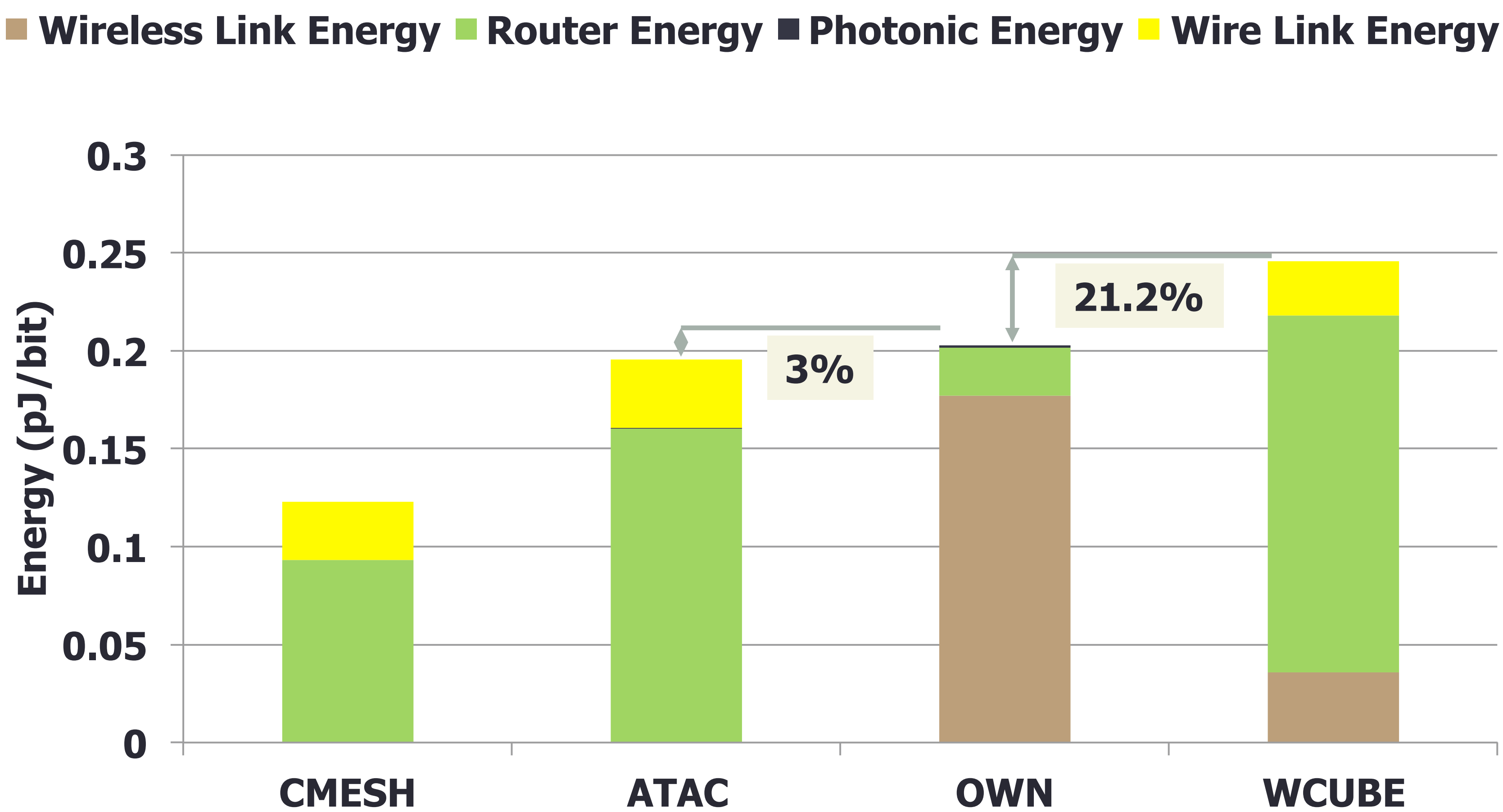
OWN requires about a 35.5% less area than ATAC

Energy per bit : Uniform



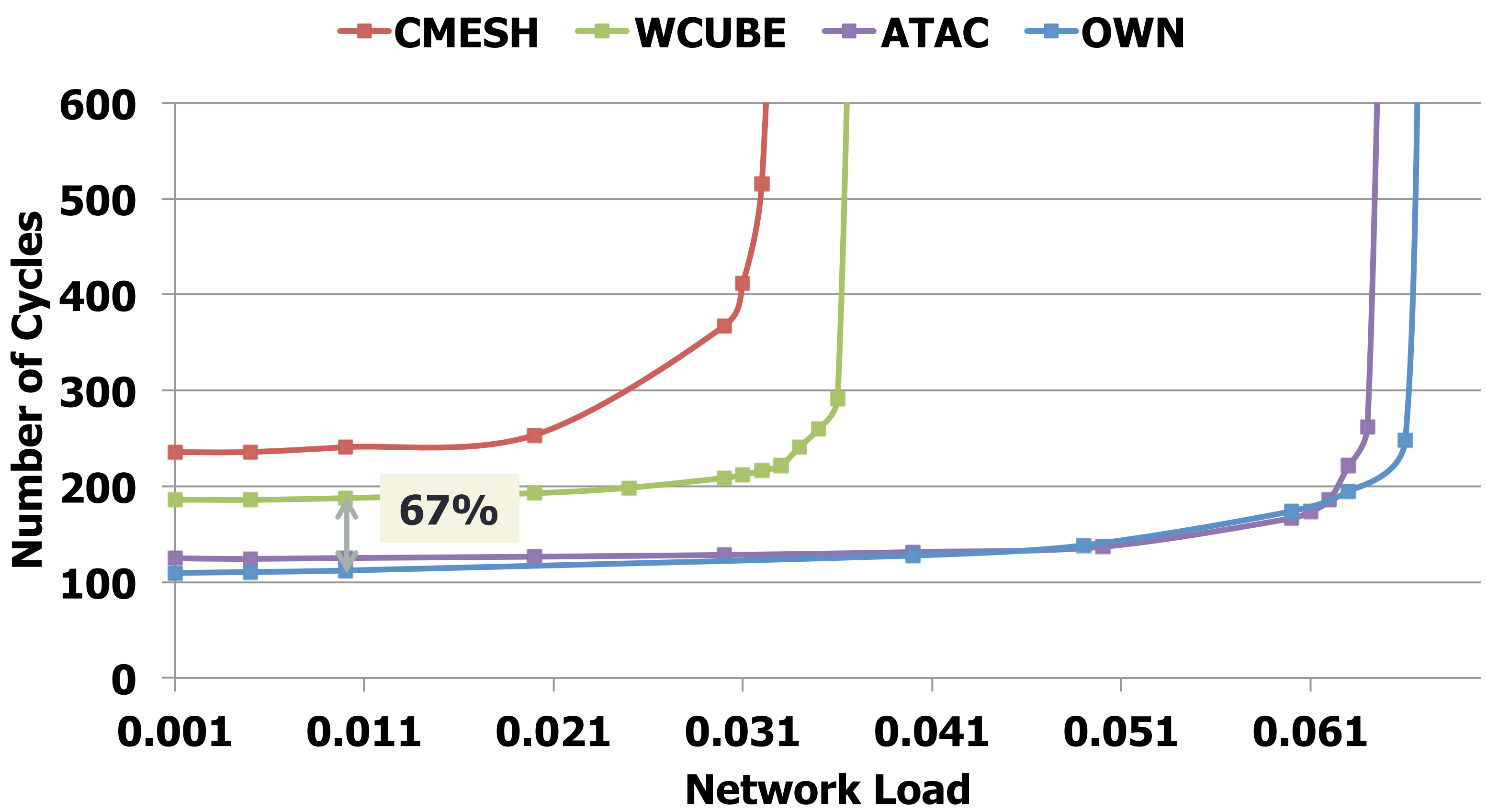
OWN consumes about a 40.2% less energy than WCube

Energy per bit : Perfect Shuffle



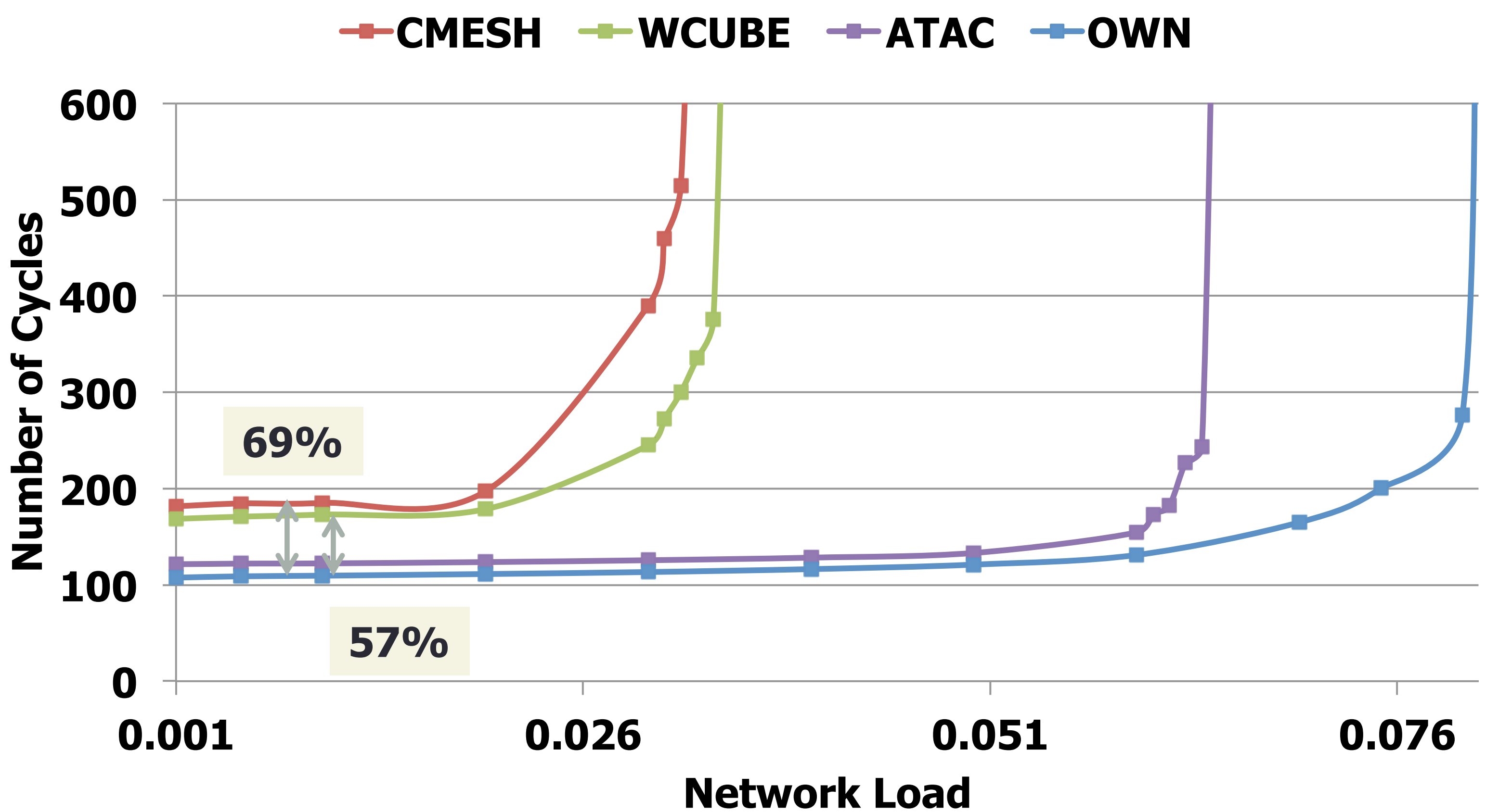
OWN consumes about a 21.2% less energy than WCube

Latency: Uniform Traffic



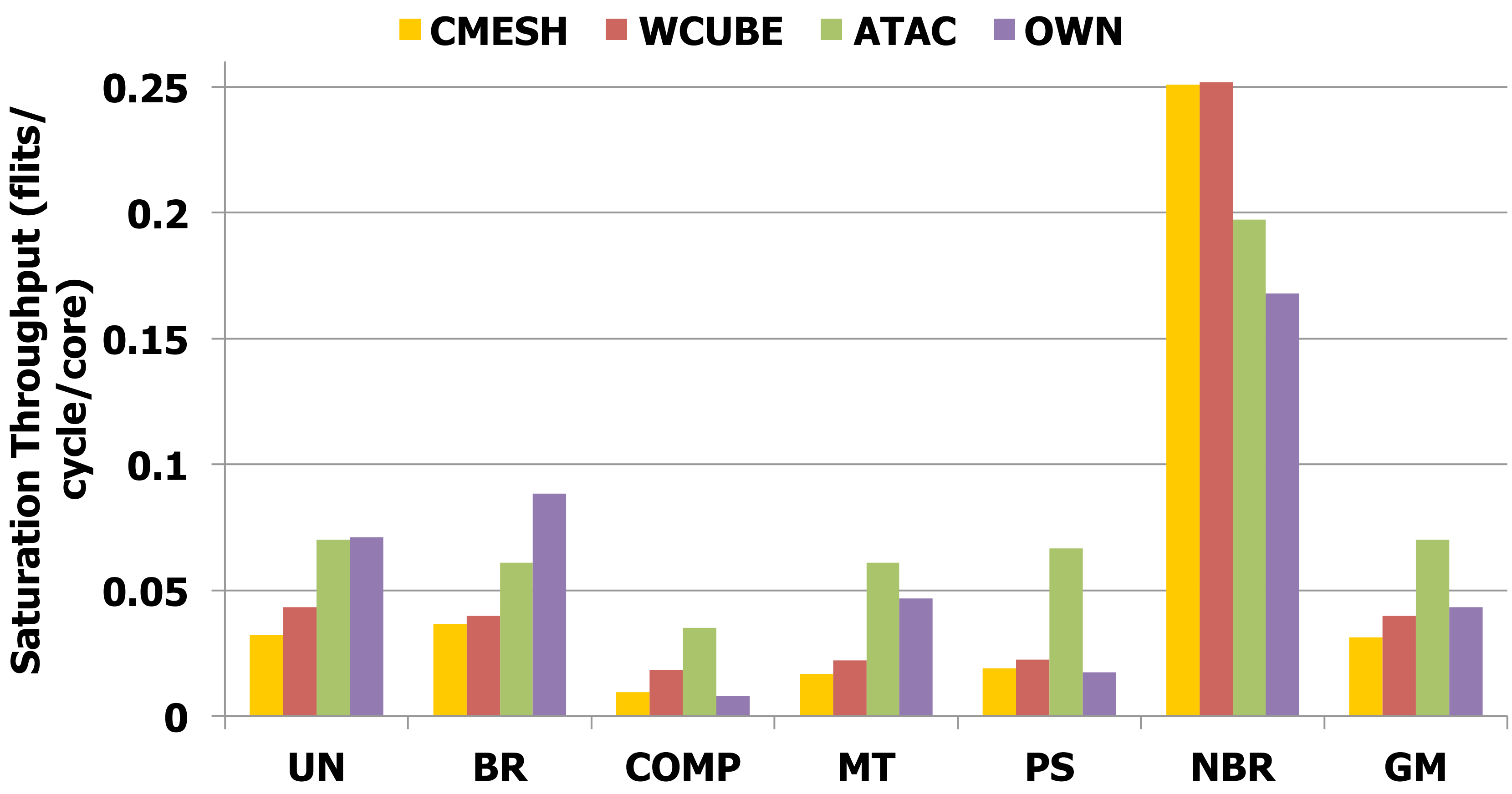
OWN lowered the latency by about 67% and 11% from Wcube and ATAC respectively

Latency: Bit-Reversal Traffic



OWN lowered the latency by about 69%, 57% and 11% from CMesh, Wcube and ATAC respectively

Saturation Throughput



OWN outperforms WCube and Cmesh on average by about 8% and 28% respectively

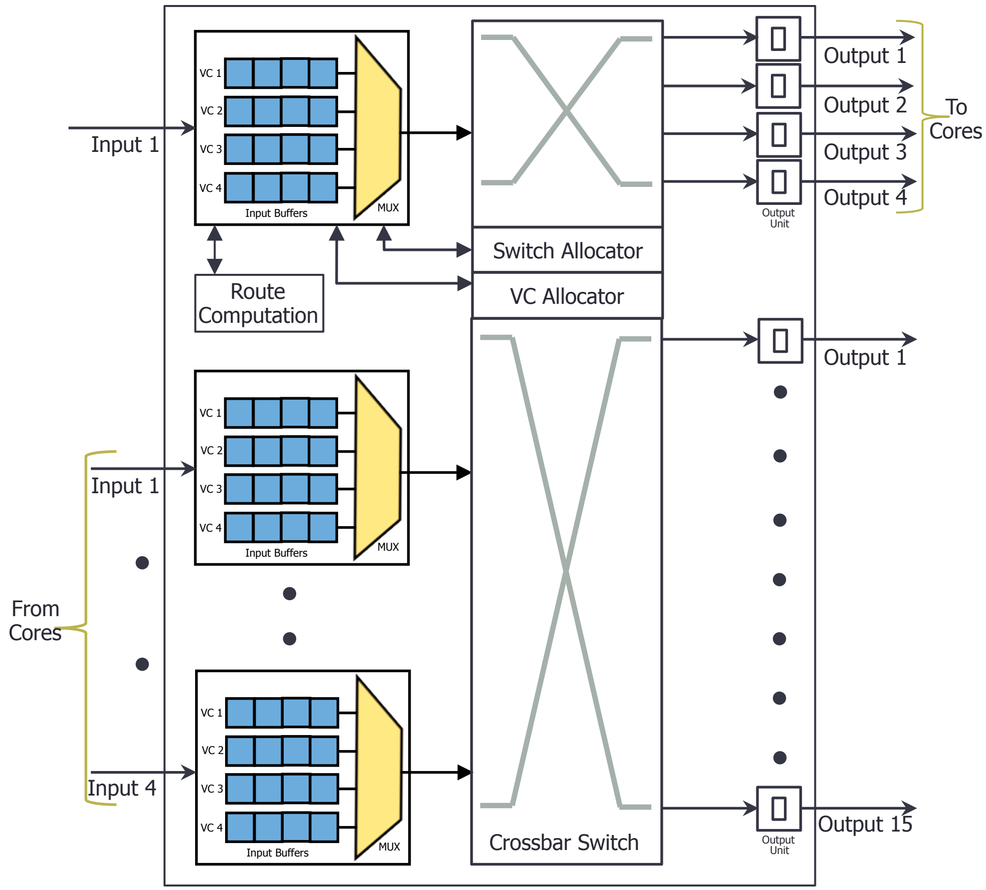
Conclusions & Future Work

- OWN requires 35.5% less area than ATAC but 34.14% higher area than WCube
- OWN requires 30.36% less energy/bit than WCube but 13.99% higher energy/bit than ATAC
- OWN has higher saturation throughput & lower latency compared to wired, wireless and optical networks
- CMOS technology advancement will benefit OWN in both area and energy/bit
- Dynamic wireless channel allocation can be a future work

Thank You

Questions?

Decomposed Crossbar Router



Optical Power Calculation

- Laser Power (one wavelength) = Longest Link x 1dB/cm + 1 dB (for modulation) + 1dB (for demodulation) + 0.0001 x ring modulator adjacent + 0.2dB (splitter) + 1dB (photodetector loss)
- Laser Efficiency = 15%
- Receiver Sensitivity = -17dBm
- Pin = 10 ^ (loss in dB / 10) x Pout
- Ptotal = #WL (Pin / Laser Eff.) + (Pin / Laser Eff.) x Arbitration Link
- Ring Heating Power = 26uW/ring
- Ring Modulating = 500uW/ring

Optical Area Calculation

- Ring Resonator diameter 12um
- WG = Width (4um) x Length