Enabling High Performance Embedded Computing through Memory Access via Photonic Interconnects

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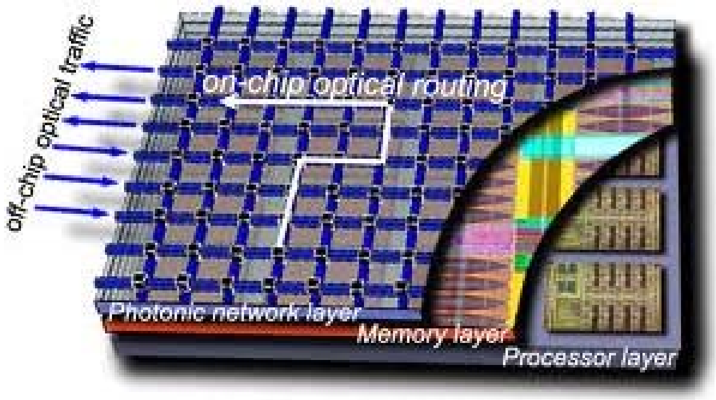
Photonics: Advantages and Disadvantages

Advantages

Very fast transfer rate

Very low latency for long distances

Low power



Disadvantages

High upfront cost in time to send a packet

High upfront cost in power to send a packet

Photonic Interconnects hold potential for on-chip computing. However, the target applications must be considered to determine if photonics will be beneficial for them

Embedded Computing: ISR Applications

Image Registration

Where is the image in relation to other images already taken?

SAR Image Formation

How many pulses can feasibly be combined and what size of an image can we take?

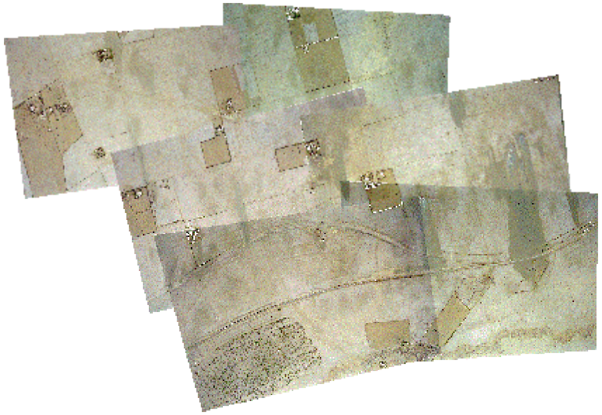


Image Sharpening

Can image fidelity be improved through using additional information or multiple pictures?

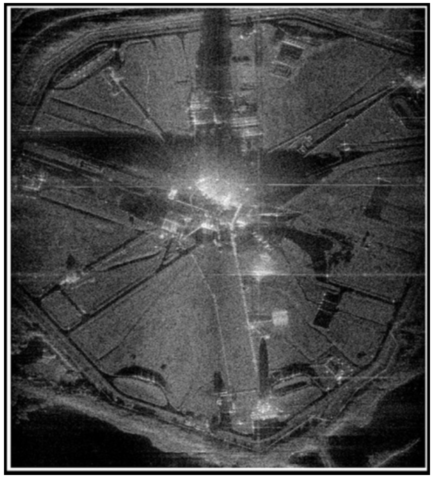
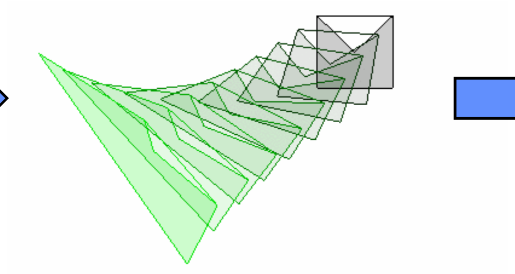


Image Registration



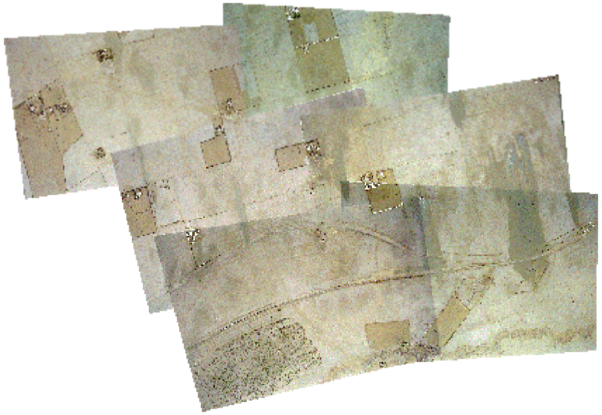


Image Registration Involves:

- **Image Orientation and Scaling**
- **Image Alignment**

Produces an image that "fits" properly with other registered images to get a global view of the area.

Image Sharpening

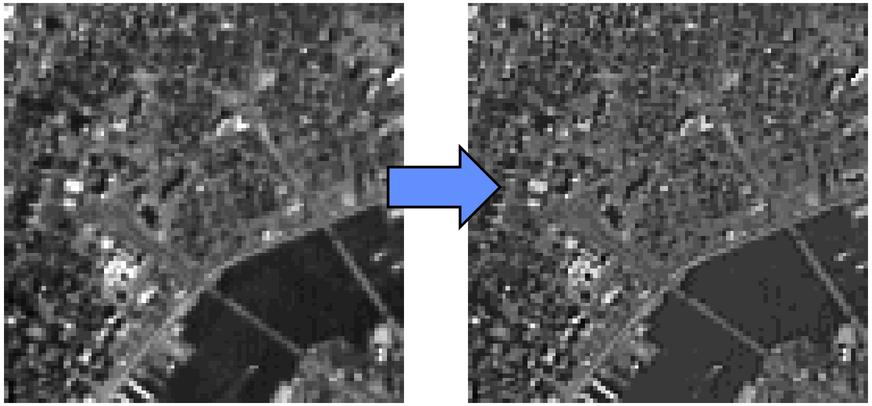


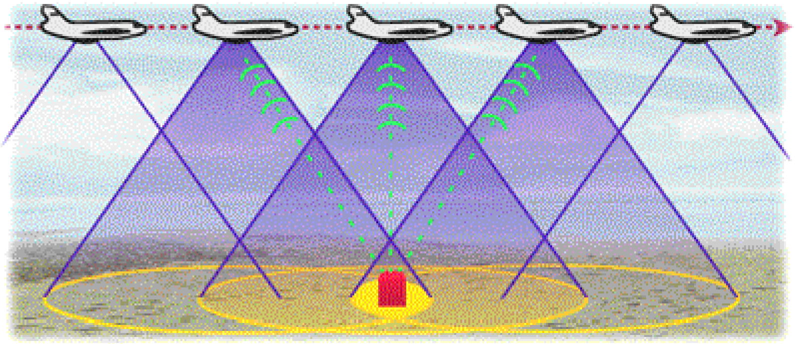
Image Fusion:

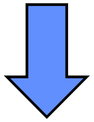
Fuses two low resolution images to form a high resolution result.

Filtering:

Enhances image fidelity by combining filters with the original image (Bicubic, Bilinear, Halfband...)

SAR Image Formation



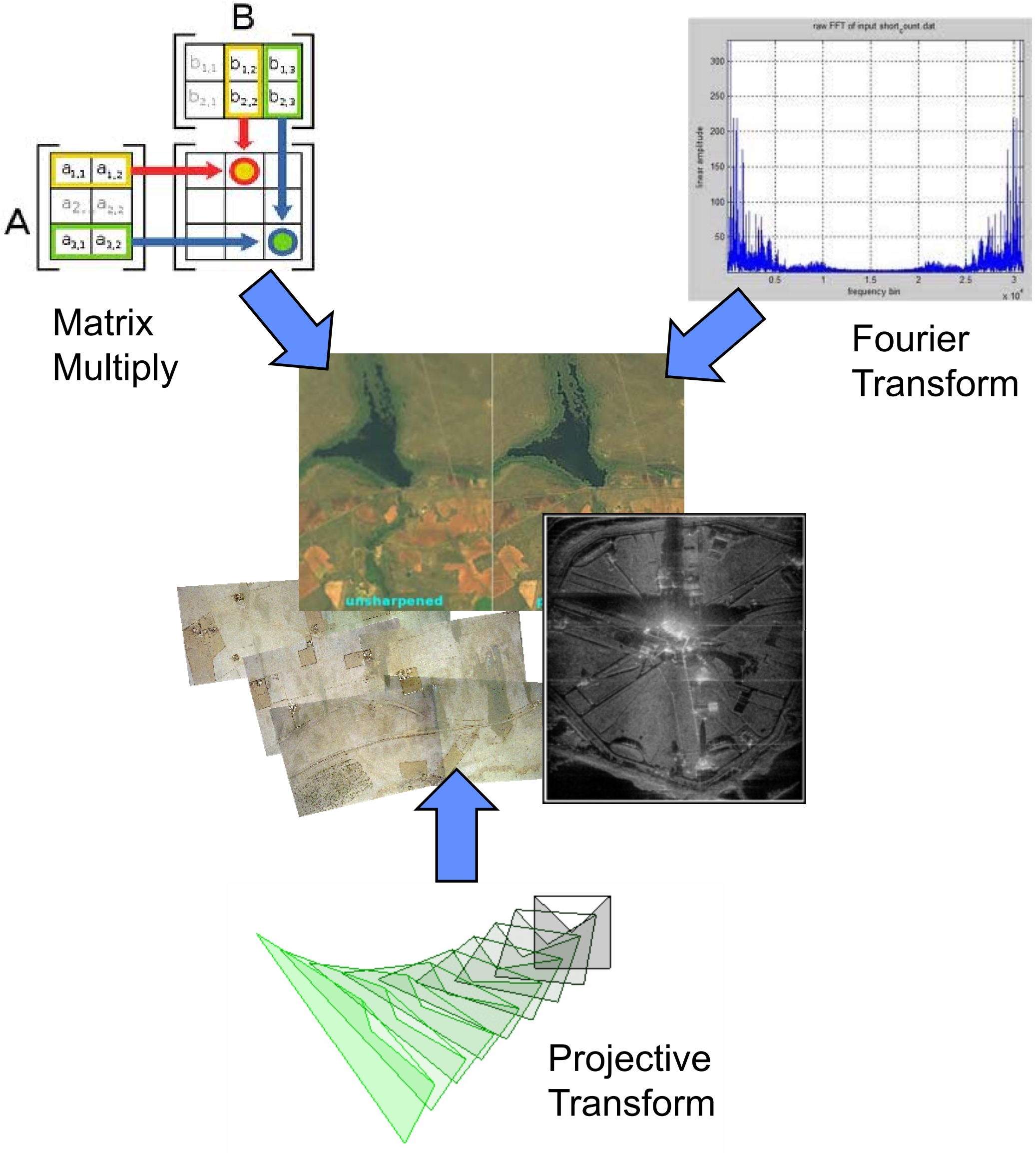


Synthetic Aperture Radar (SAR) is an imaging technique that uses RADAR pulses rather than photography

SAR Processing:

- **Image formation nontrivial, requires combining pulses**
- **The more pulses that can be processed, the higher the image resolution**
- **SAR can operate in conditions where traditional photography fails (low light, cloud cover)**

ISR Application Kernels



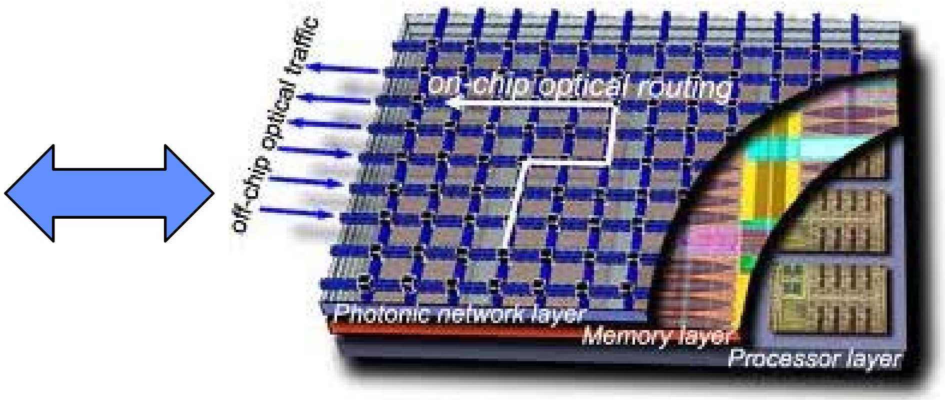
ISR Kernels:

- **Matrix Multiply, Projective Transform, Fourier Transform**
- **Used in a broad range of ISR applications**
- **Typically a performance bottleneck**
- **Demand high throughput from the memory and network modules**

Characteristics of ISR Applications

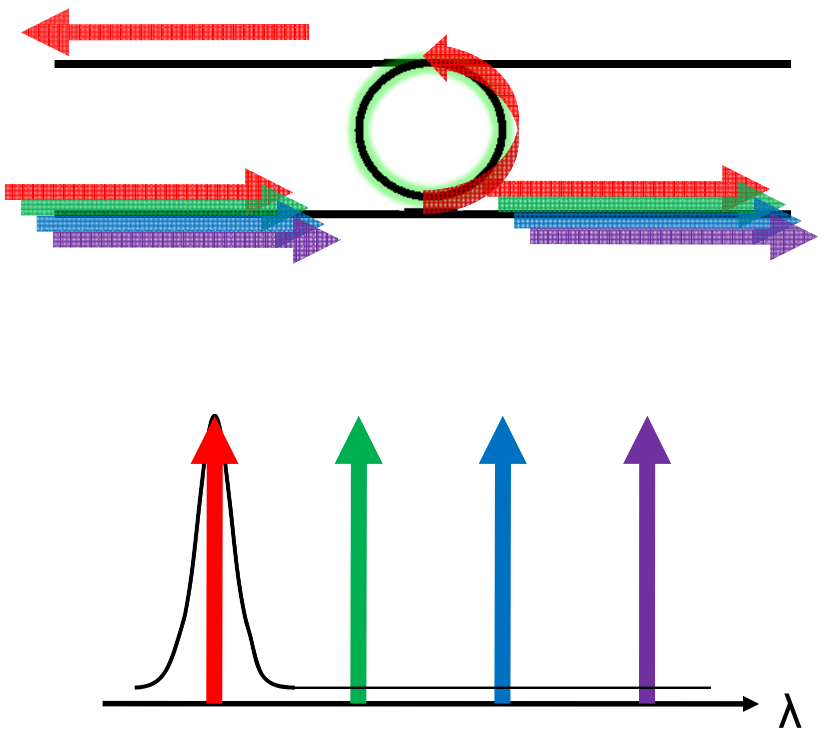
ISR Applications Ideal Candidates for Photonic Interconnects

- **Large Memory Access Size**
- **Low Power Requirements**
- **High Memory Access to Compute Ratio**
- **High Throughput Requirements**

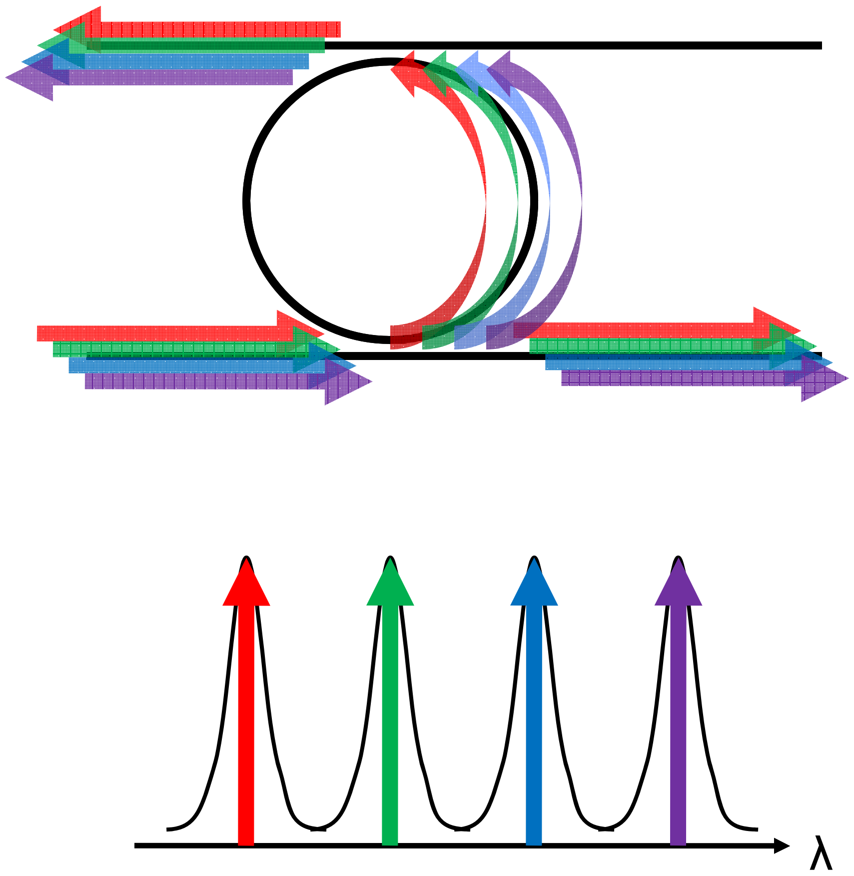


Ring Resonators

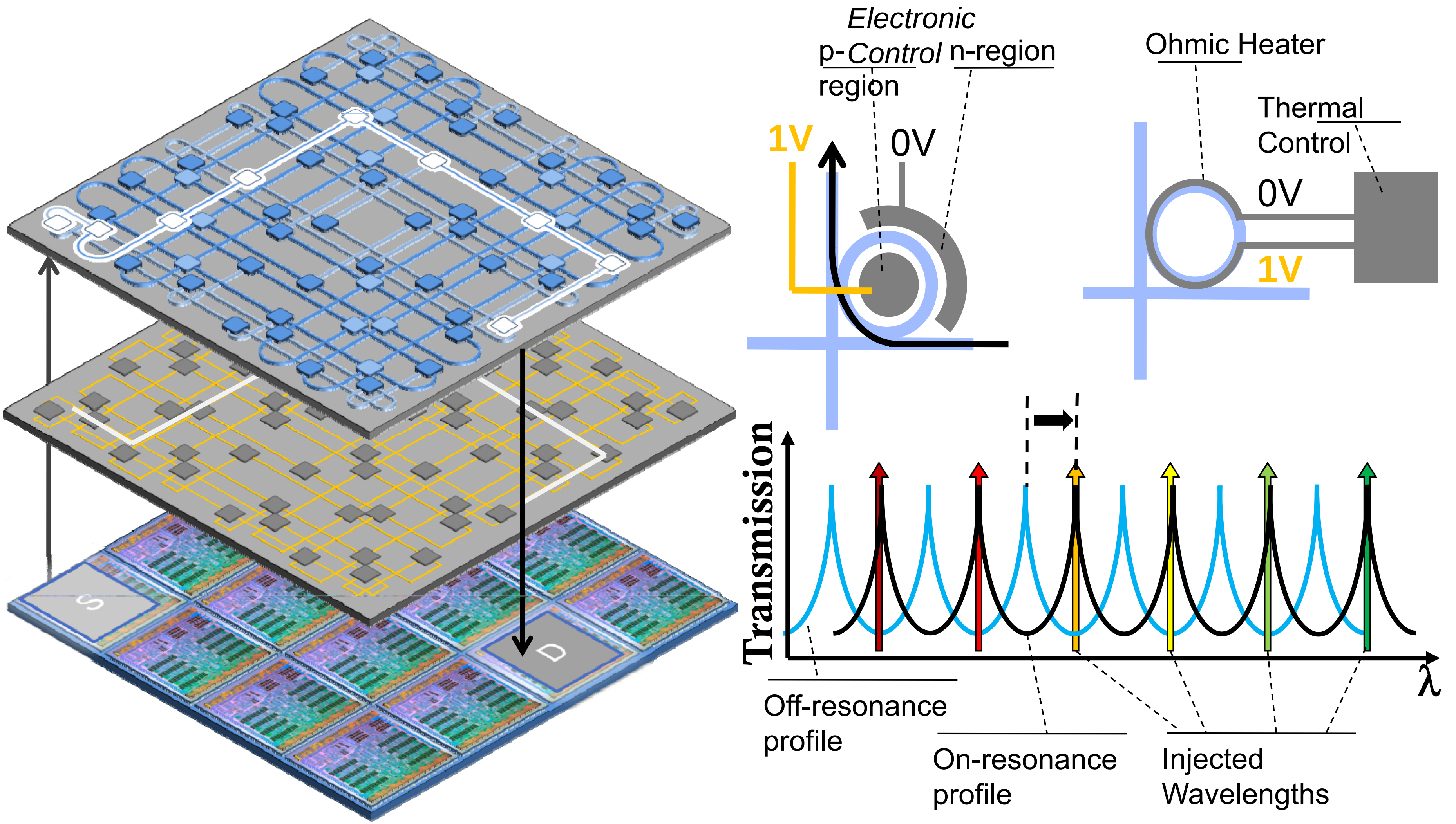
- **Modulator/filter**



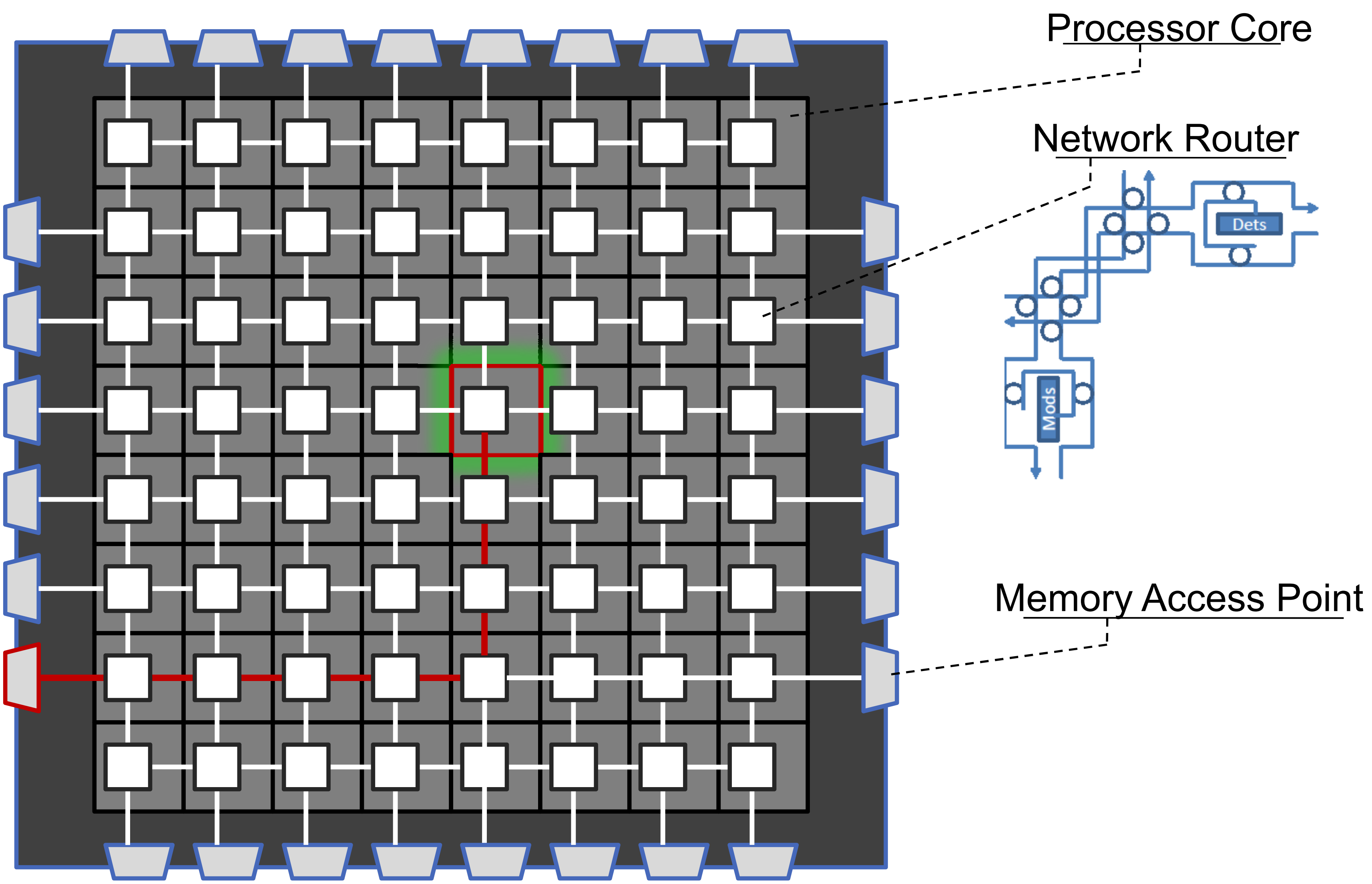
- Broadband



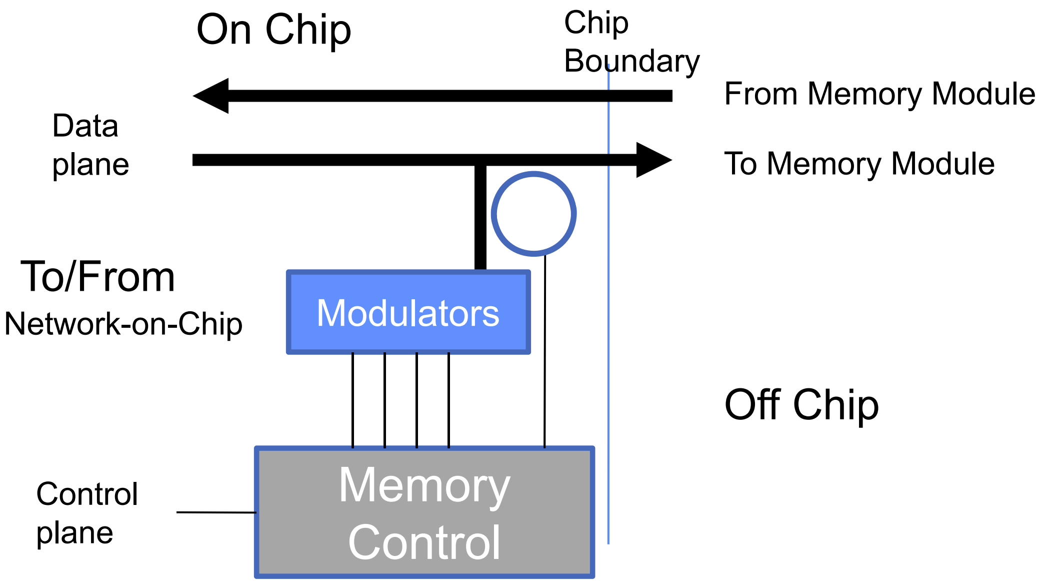
Circuit-switched P-NoCs

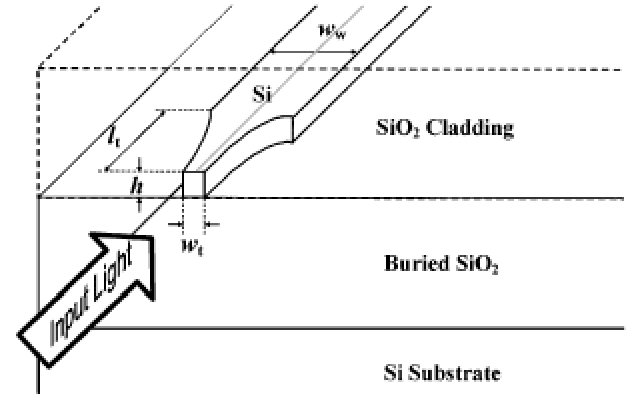


Peripheral Memory Access

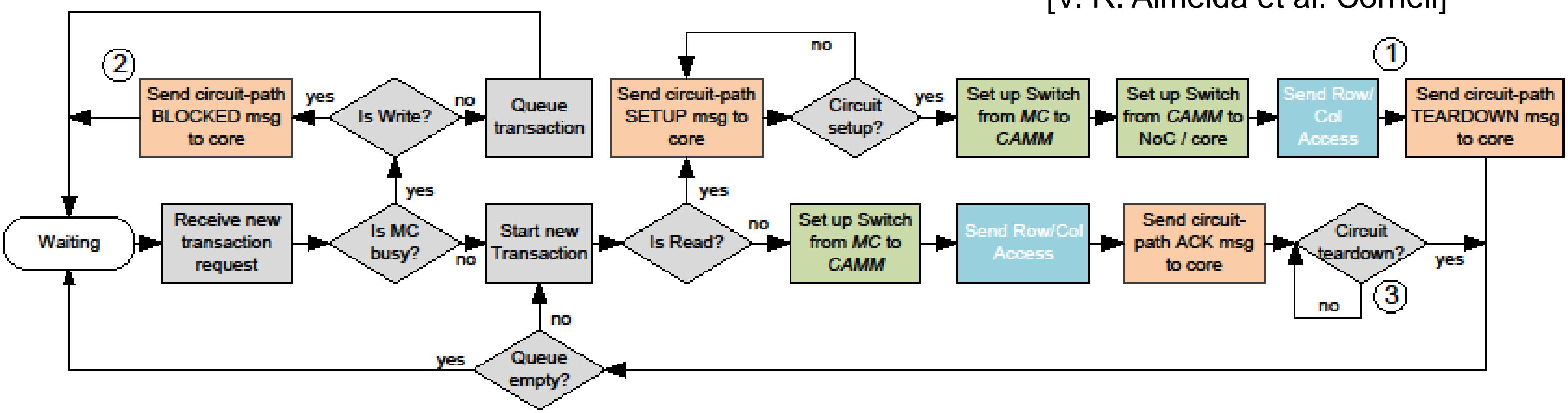


Memory Access Point

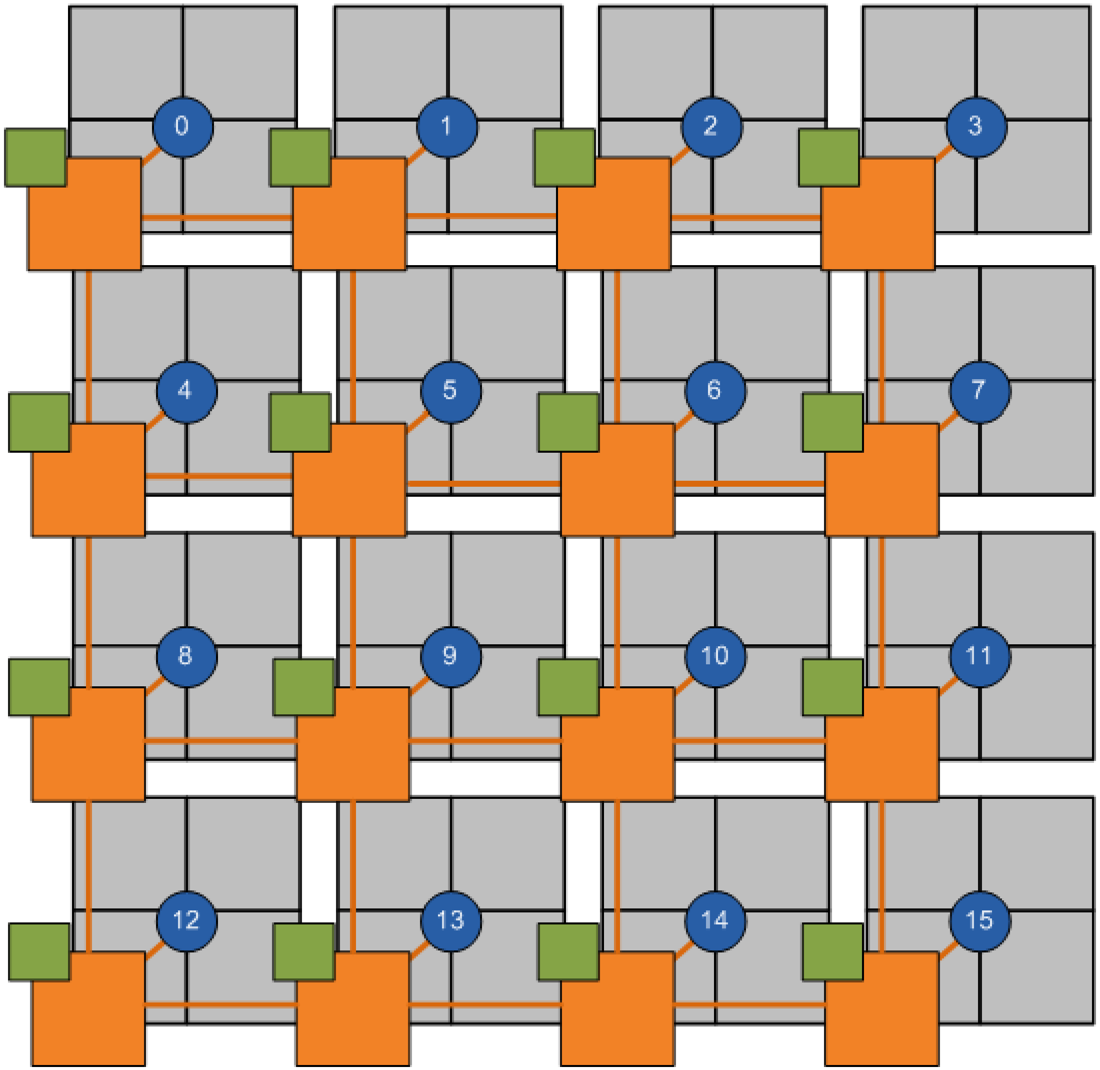


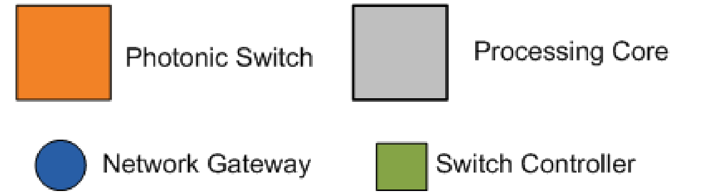


[V. R. Almeida et al. Cornell]

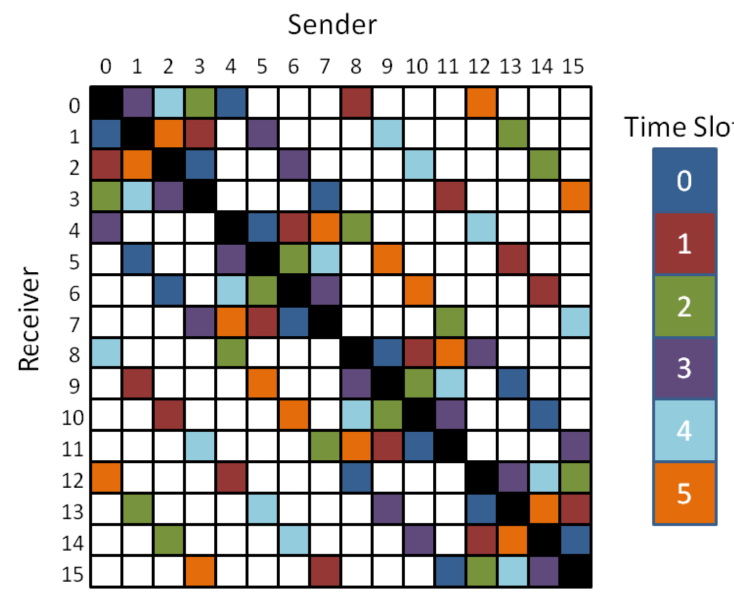


Photonic TDM Network

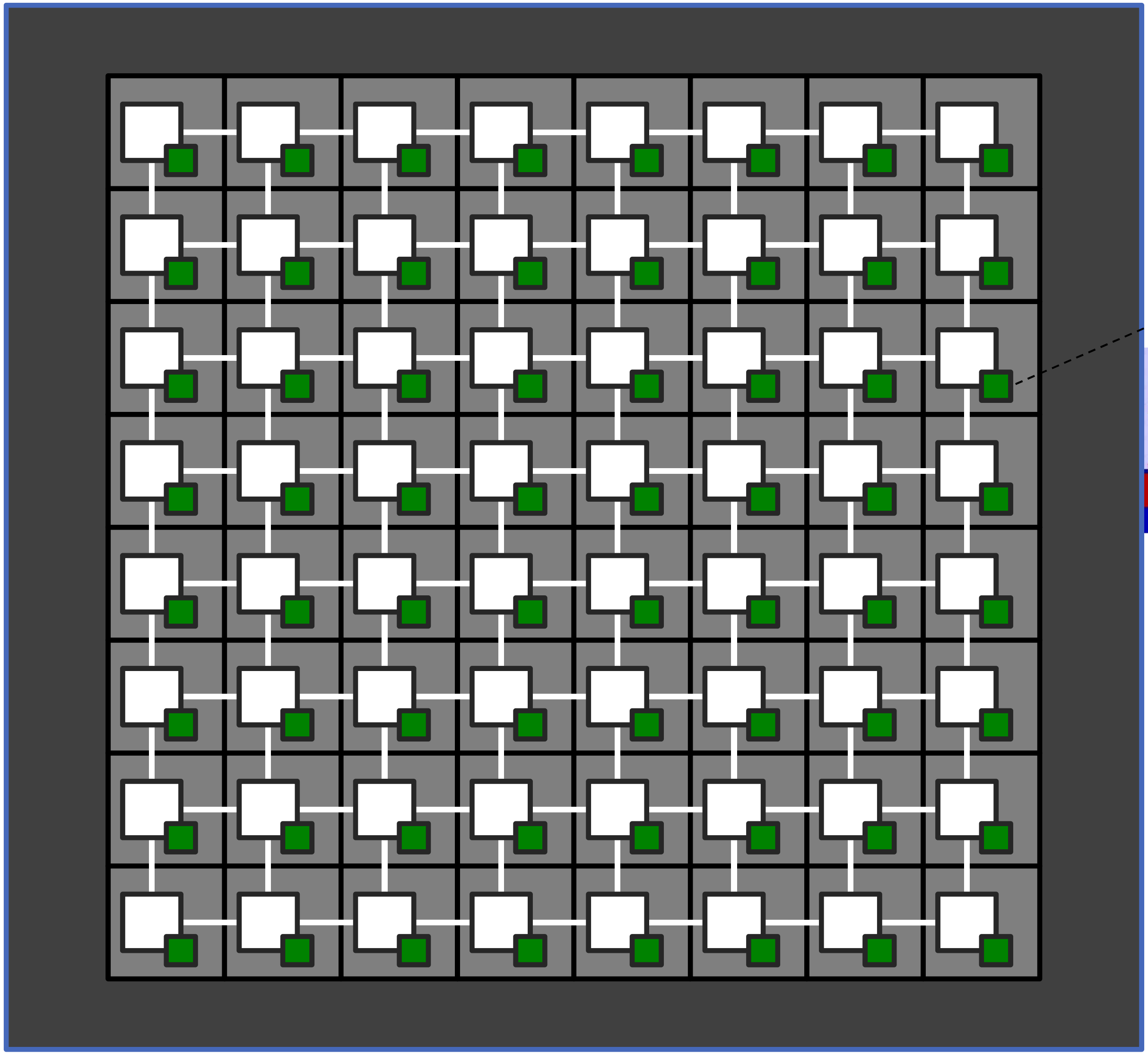


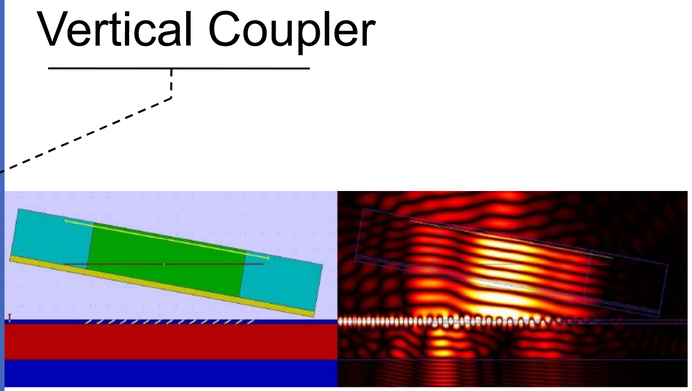


- Mesh topology
- Distributed switch control
- Single dimension transmission
- Controlled by fixed time slots :



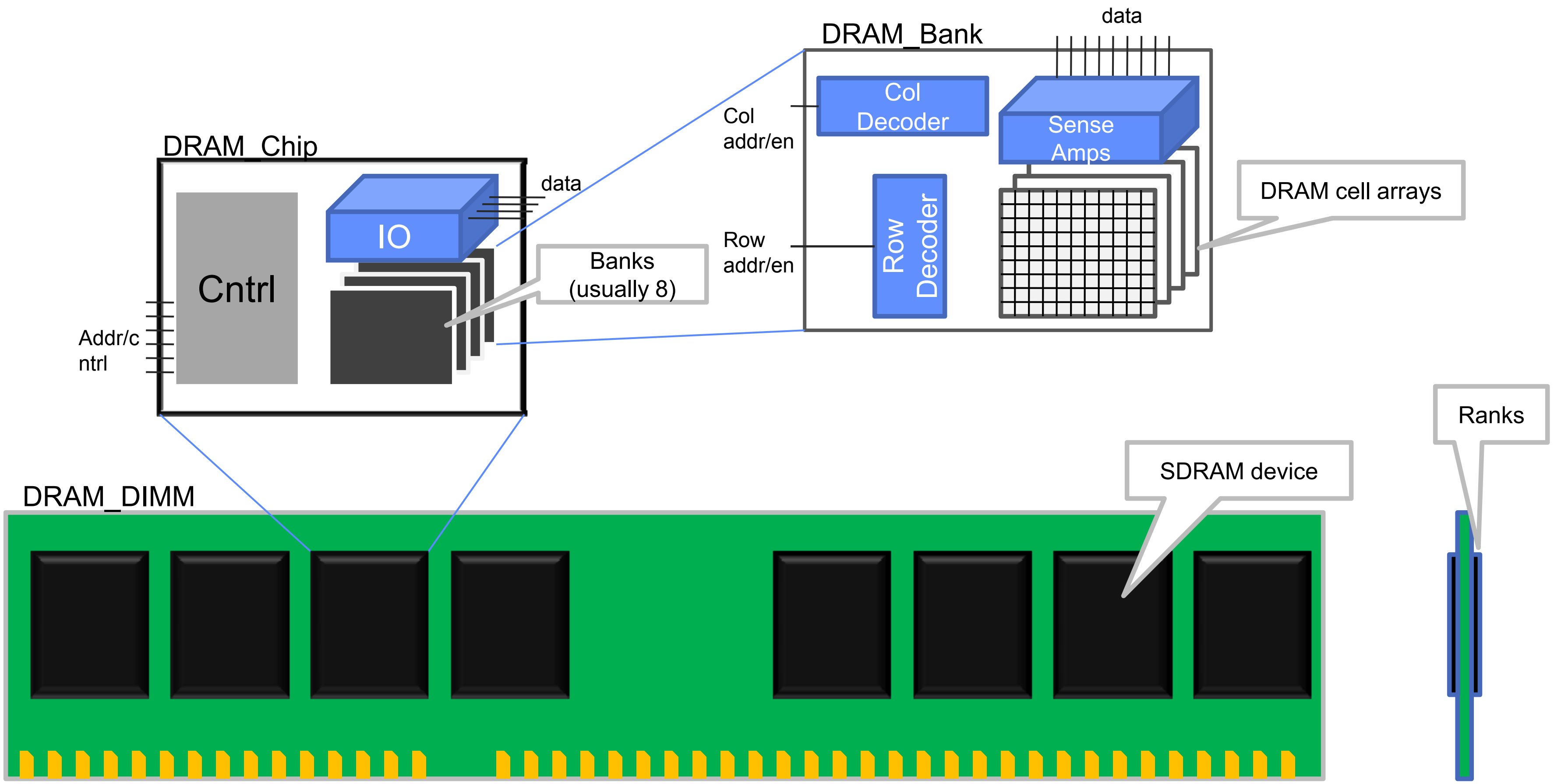
Vertical Memory Access



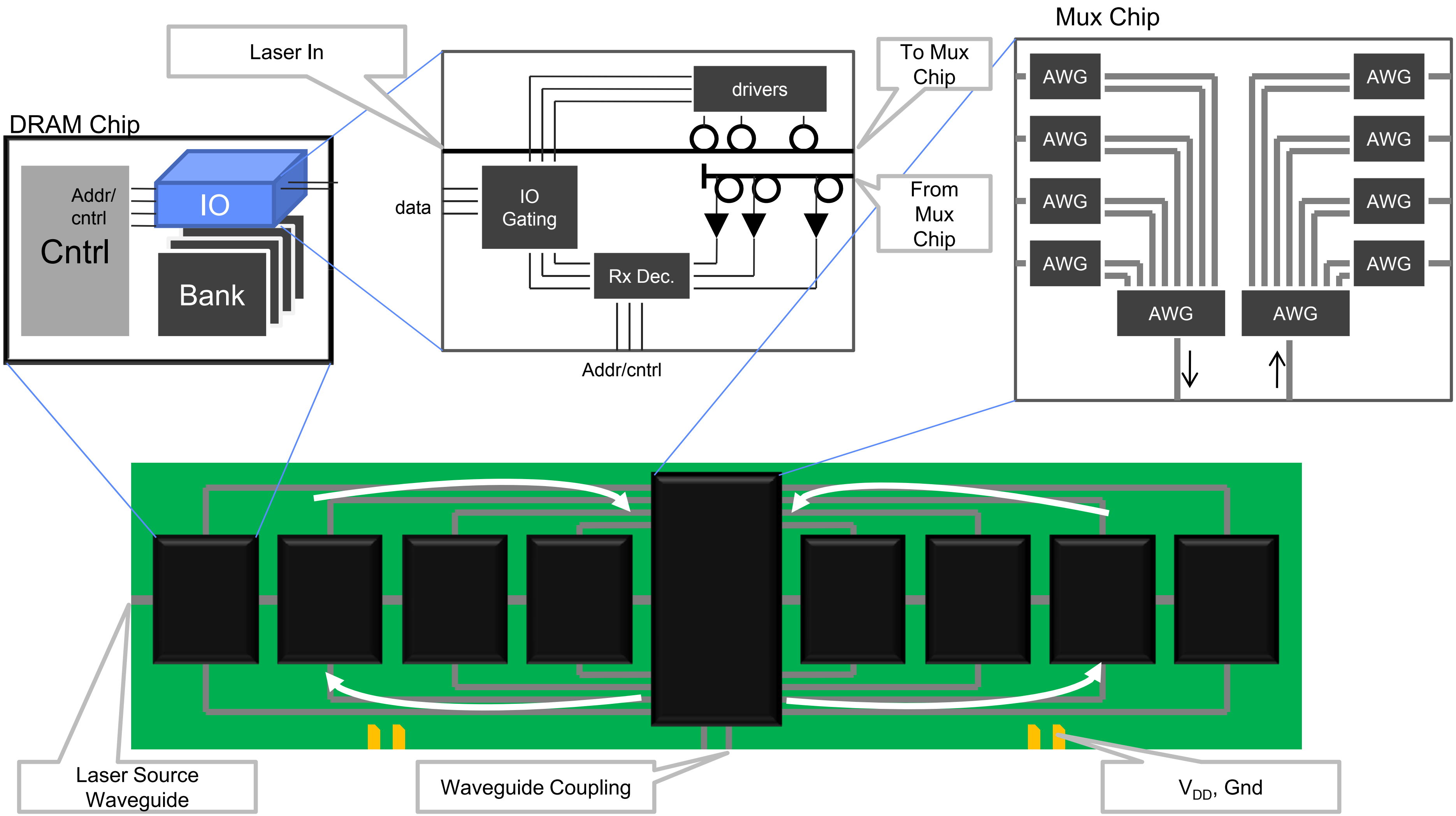


[J. Schrauwen et al. U of Ghent.]

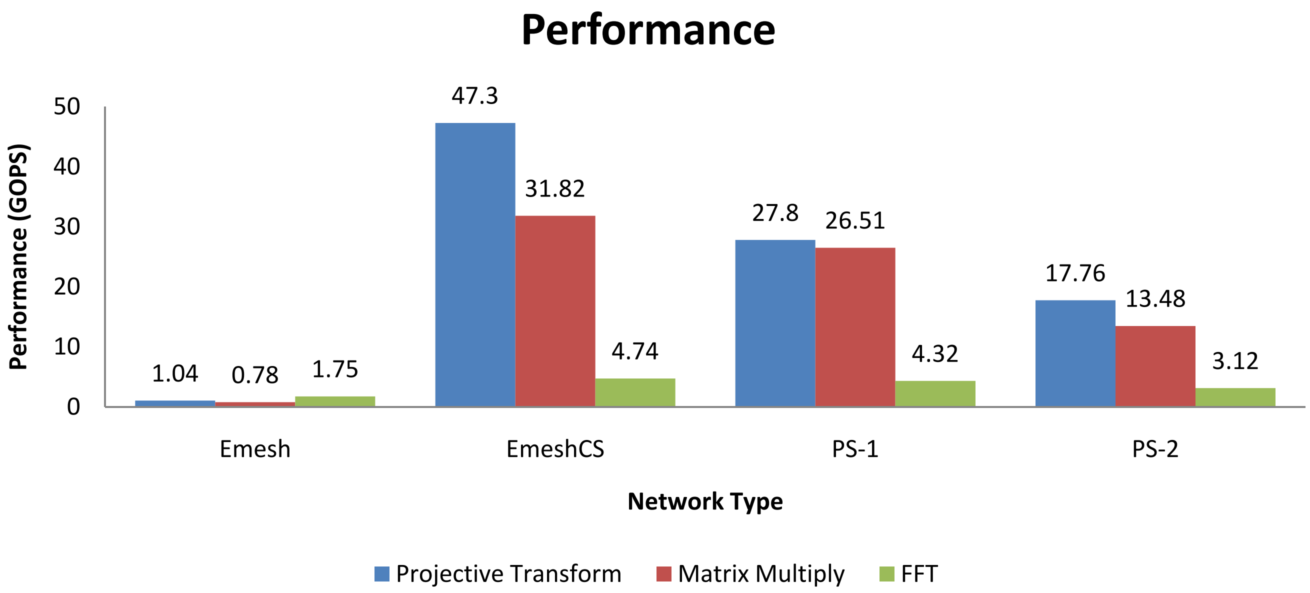
SDRAM DIMM Anatomy



Optical Circuit Memory (OCM) Anatomy



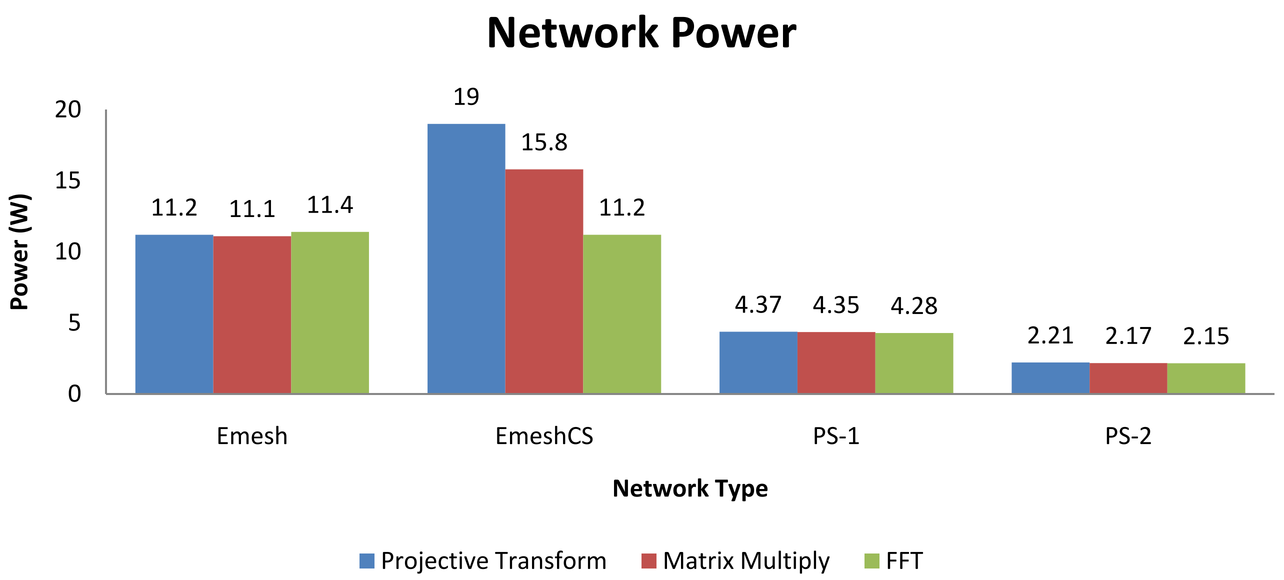
Results: *Circuit Switched* Application Performance



	Projective Transform			Matrix Multiply			FFT		
Network	*Power (Watts)*	*Perf. (GOPS)*	*Impr. (GOPS/W)*	*Net. Pow. (Watts)*	*Perf. (GOPS)*	*Impr. (GOPS/W)*	*Power (Watts)*	*Perf. (GOPS)*	*Impr. (GOPS/W)*
Emesh	11.2	1.04	1x	11.1	0.78	1x	11.4	1.75	1x
EmeshCS	19.0	47.3	26.9x	15.8	31.82	29.01x	11.2	4.74	2.82x
PS-1	4.37	27.80	68.6x	4.35	26.51	87.64x	4.28	4.32	6.72x
PS-2	2.21	17.76	86.7x	2.17	13.48	89.33x	2.15	3.12	9.67x

EmeshCS yields the best performance, but PS-1 and PS-2 are competitive

Results: *Circuit Switched* Power



	Projective Transform			Matrix Multiply			FFT		
Network	*Power (Watts)*	*Perf. (GOPS)*	*Impr. (GOPS/W)*	*Net. Pow. (Watts)*	*Perf. (GOPS)*	*Impr. (GOPS/W)*	*Power (Watts)*	*Perf. (GOPS)*	*Impr. (GOPS/W)*
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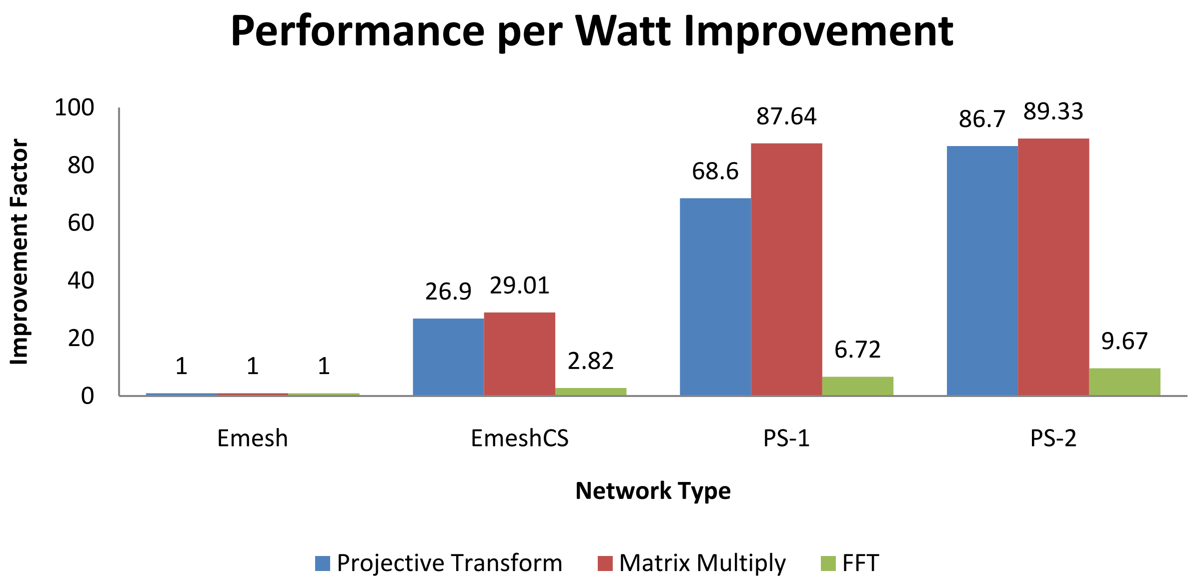
PS-2	2.21	17.76	86.7x	2.17	13.48	89.33x	2.15	3.12	9.67x

PS-1 and PS-2 use much less power than electronic alternatives

Results: *Circuit Switched* Performance/Watt Comparison



	Projective Transform			Matrix Multiply			FFT		
Network	*Power (Watts)*	*Perf. (GOPS)*	*Impr. (GOPS/W)*	*Net. Pow. (Watts)*	*Perf. (GOPS)*	*Impr. (GOPS/W)*	*Power (Watts)*	*Perf. (GOPS)*	*Impr. (GOPS/W)*
Emesh	11.2	1.04	1x	11.1	0.78	1x	11.4	1.75	1x
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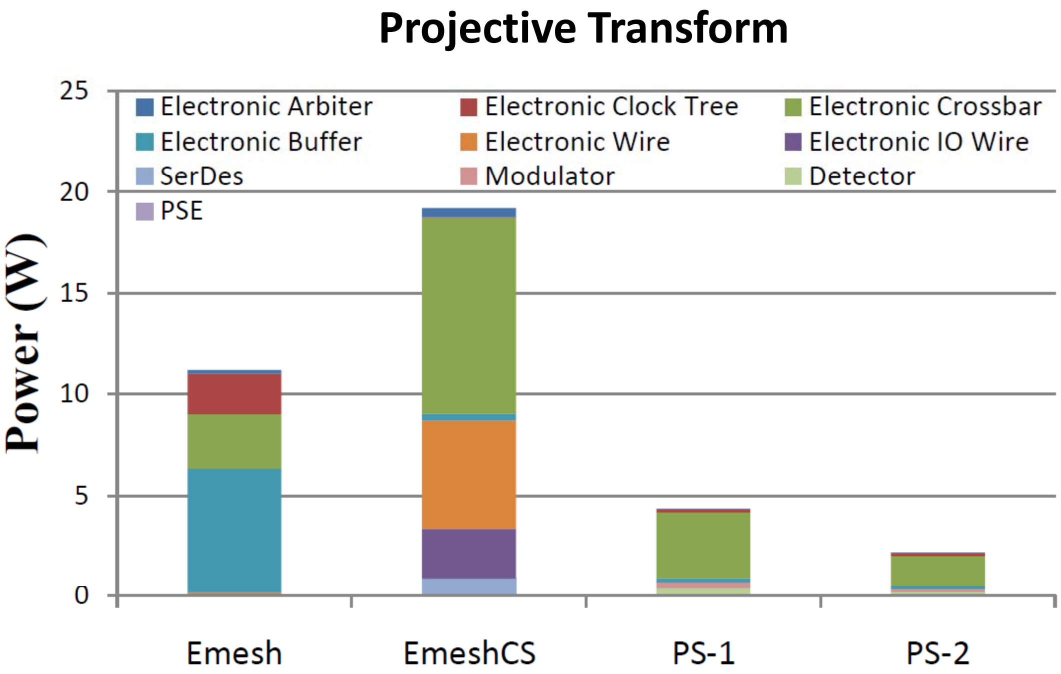
PS-1	4.37	27.80	68.6x	4.35	26.51	87.64x	4.28	4.32	6.72x
PS-2	2.21	17.76	86.7x	2.17	13.48	89.33x	2.15	3.12	9.67x

PS-1 and PS-2 give the best performance per unit of power

Results: *Circuit Switched* Power Budget Breakdown



The Electronic Crossbar requires a significant amount of power. However, in the Electronic Mesh, the Electronic Buffers dominate the energy consumption

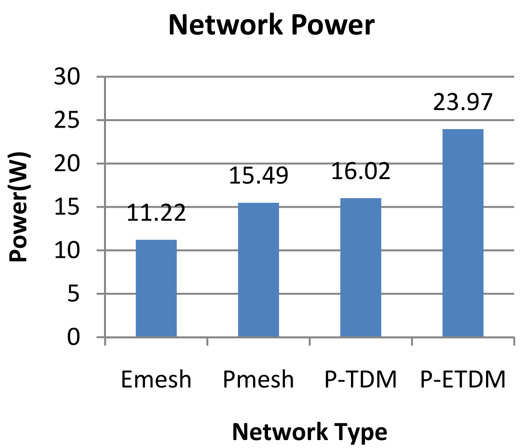
Electronic components dominate the power of all the systems in question

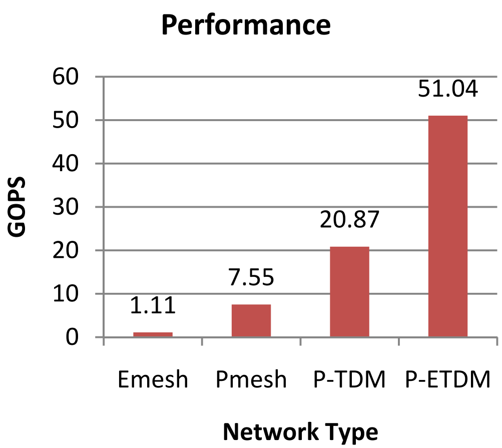
PS-1 and PS-2 both dominated by Electronic Crossbar

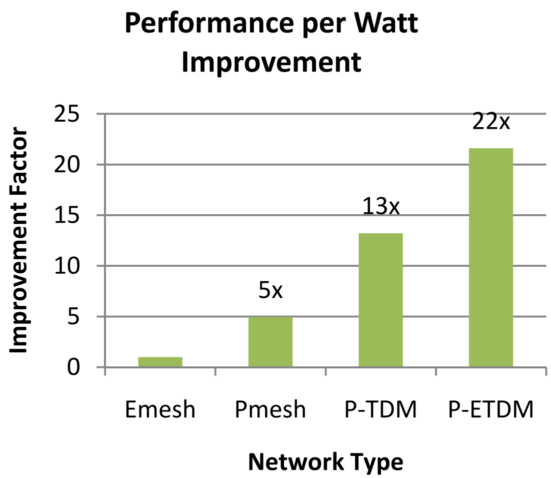
Emesh dominated by Electronic Buffer

EmeshCS dominated by Crossbar and Electronic Wire

Results: *TDM* Projective Transform

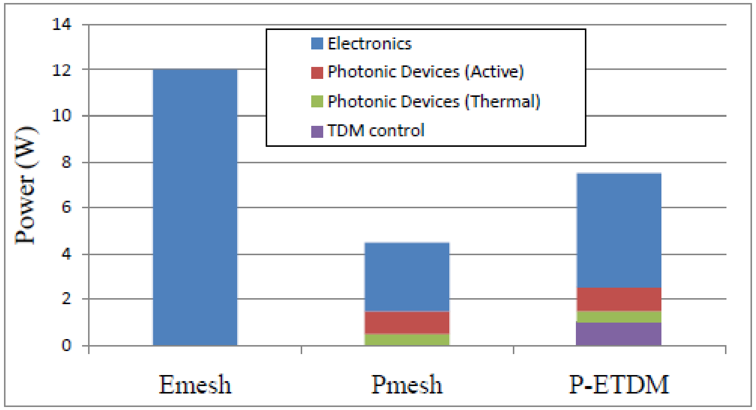






TDM Results:

- **Performed on a smaller image (256x256)**
- **Yields the best performance when packets can be sent in a single time slice**
- **Constant setup cost means smaller packages can be sent with less overhead**



TDM yields advantages when message sizes are smaller

Conclusions

- **ISR front-end application performance is of increasing importance in the community**
- **These applications put large demands on the memory and network subsystems**
- **Photonics offers a low-powered approach to meeting these performance demands**

For the full details on these photonic architectures, see our other publications in the Journal of Parallel and Distributed Computing (JPDC) 2011 and Supercomputing (SC) 2010

References

- TDM Arbitration in a Silicon Nanophotonic Network-On-Chip for High Performance CMPs
Gilbert Hendry, Eric Robinson, Vitaliy Gleyzer, Johnnie Chan, Luca P. Carloni, Nadya Bliss, Keren Bergman
Journal of Parallel and Distributed Computing 2011

- Circuit-Switched Memory Access in Photonic Networks-on-Chip for High Performance Embedded Computing
Gilbert Hendry, Eric Robinson, Vitaliy Gleyzer, Johnnie Chan, Luca P. Carloni, Nadya Bliss, Keren Bergman
Supercomputing 2010