TDM Photonic Network using Deposited Materials

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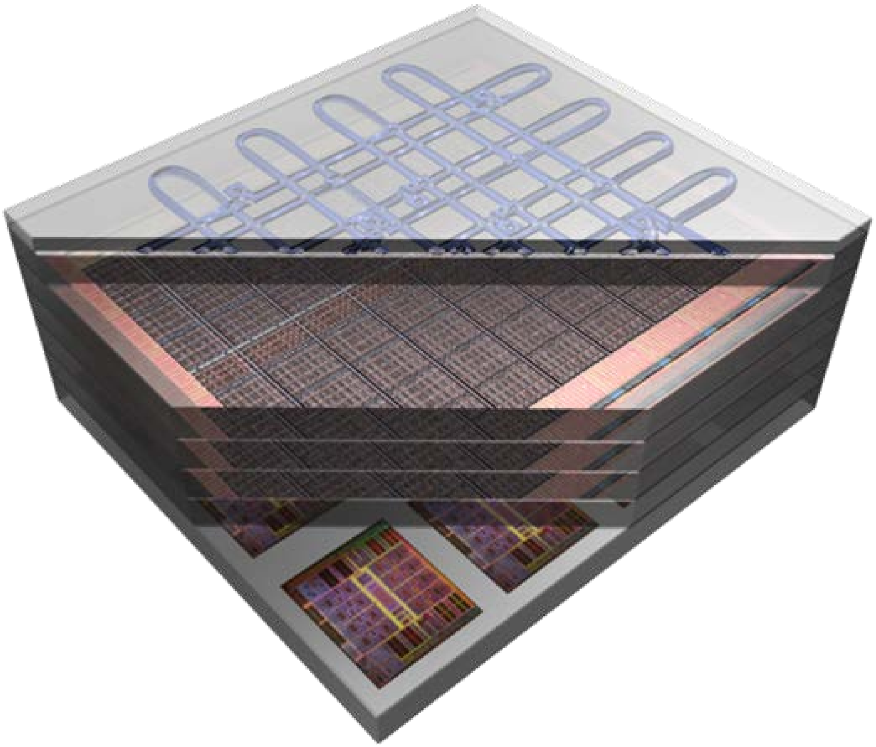
Motivation for Silicon Photonics

- Performance scaling becoming extremely difficult
  - Data movement cost increasingly expensive
  - On/off-chip communication bandwidth limited

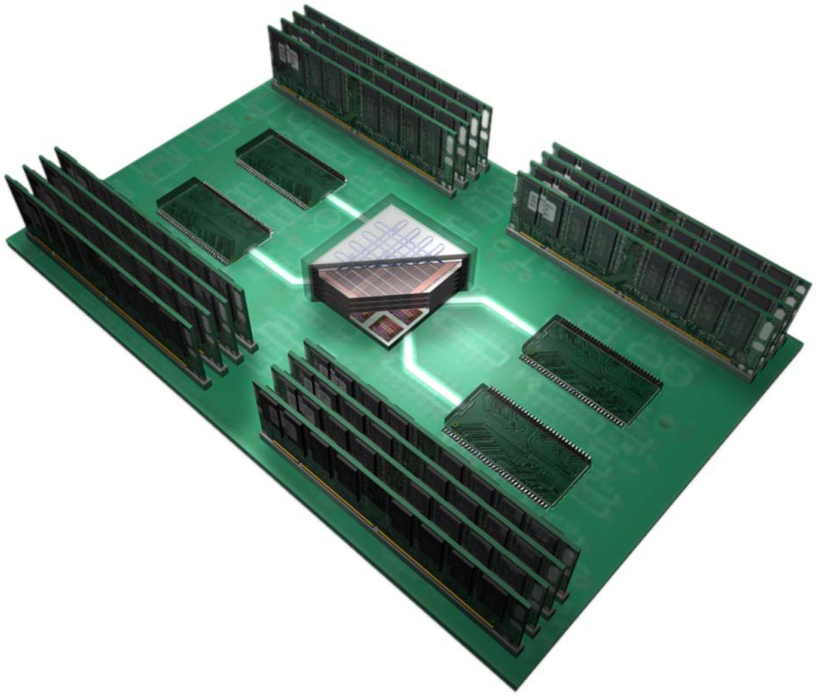
- Photonics offers:
  - Higher bandwidth density
    - High datarate and parallel wavelengths
  - Low operating power
  - Low latency

Target Architectures

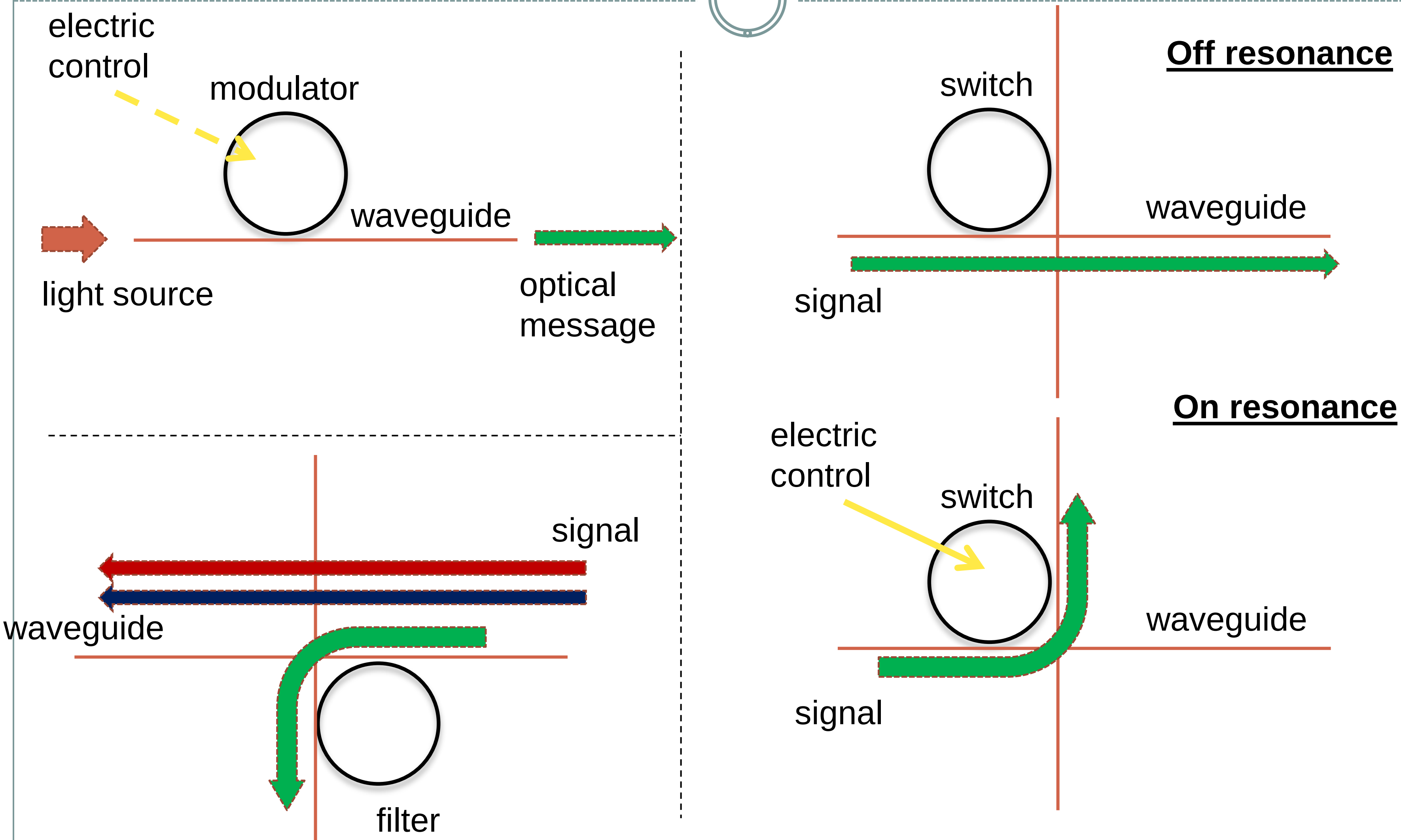
Optical interconnection network on stacked memory



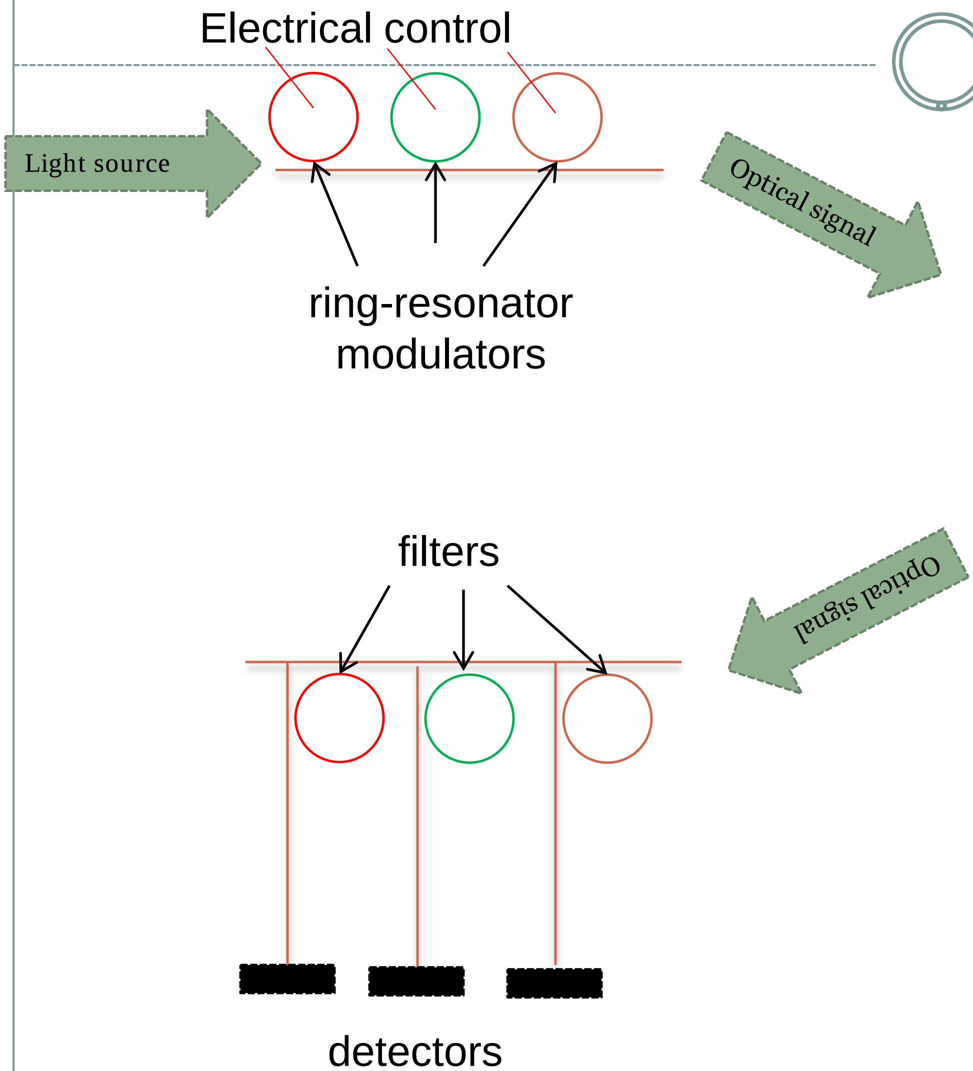
Optical link to memory

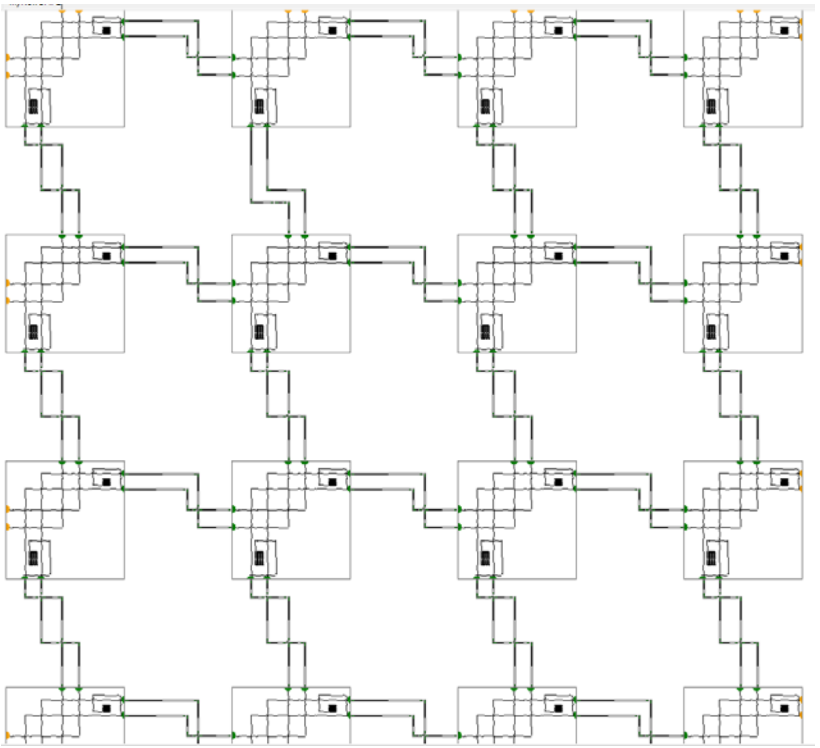


Ring Resonators



Photonic Communication





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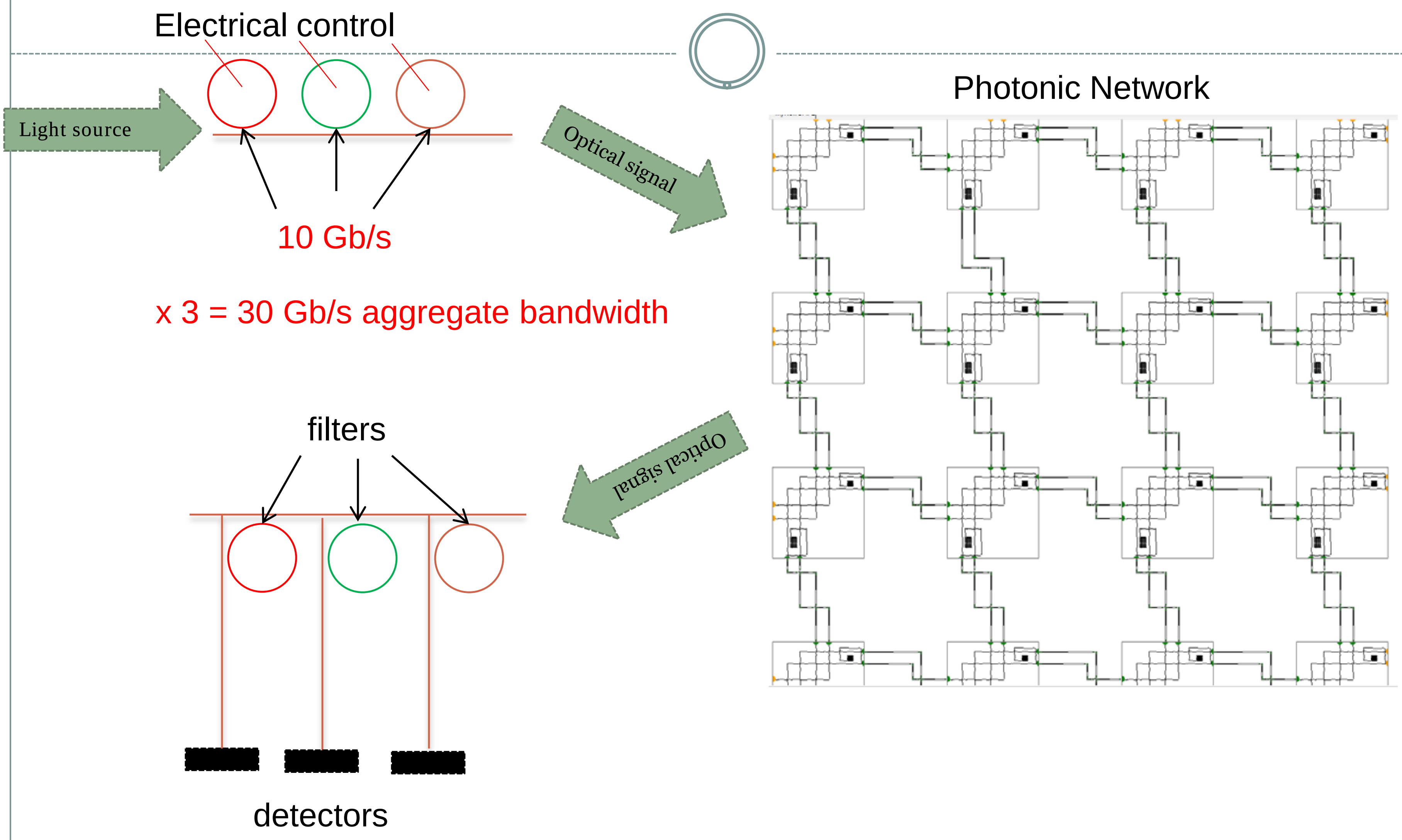
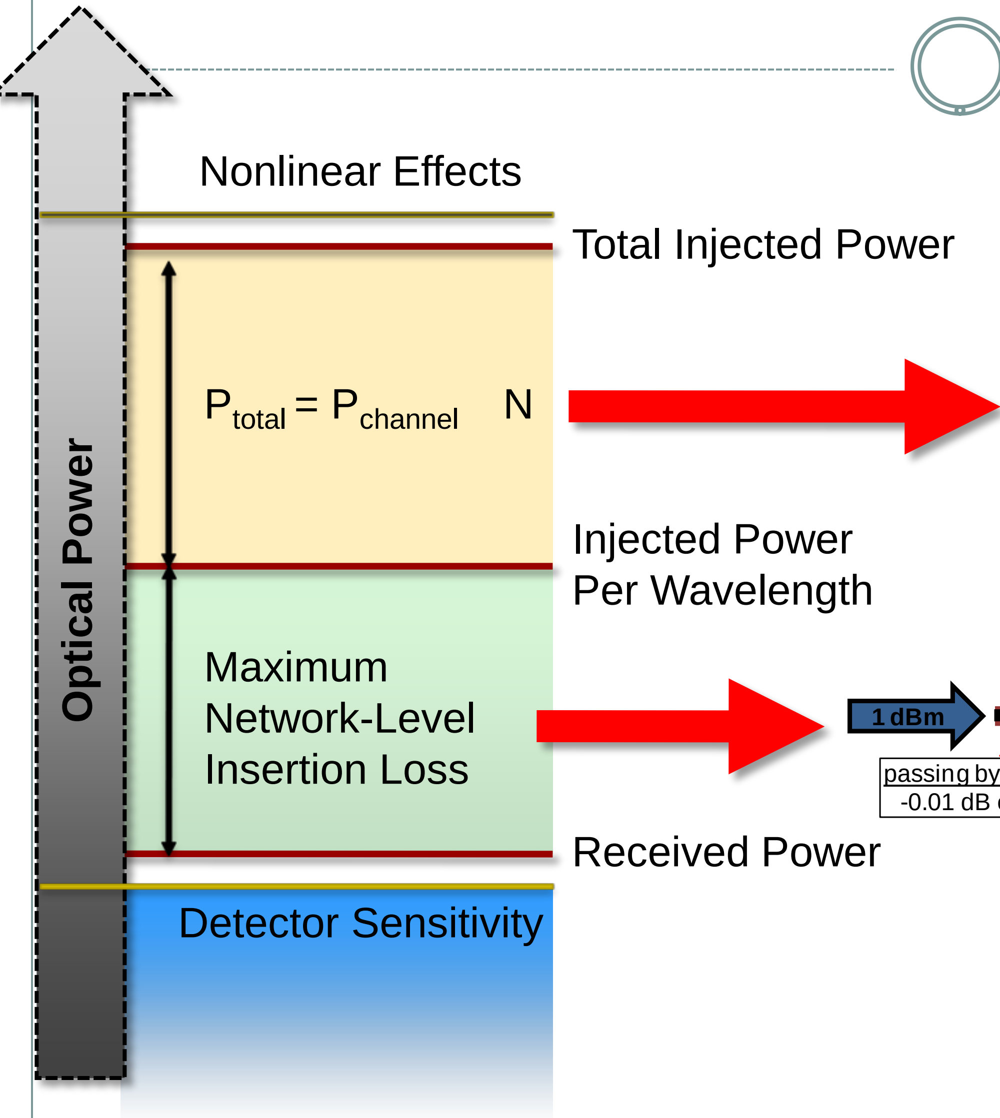
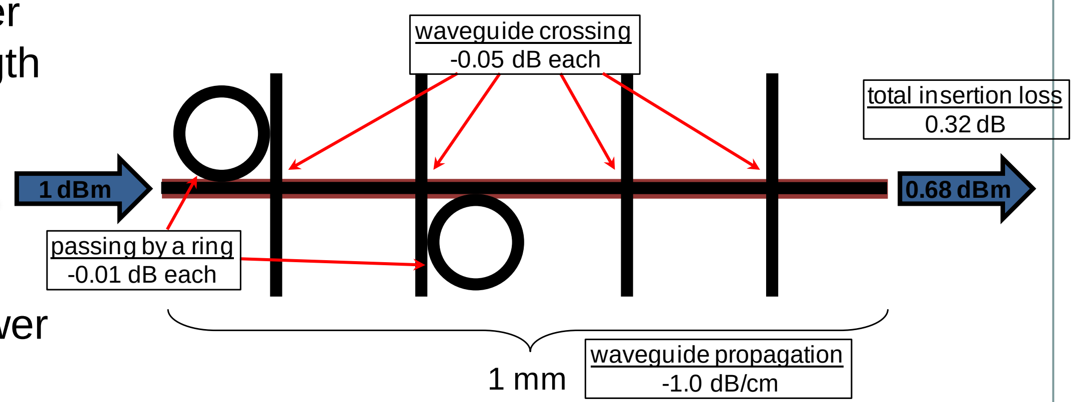


Optical Power Budget



The total injectable power P_{total} must remain below a threshold to avoid non-linear effects. P_{total} is then divided among the N wavelengths of a WDM packet, where each channels injects at $P_{channel}$.



Silicon Photonics Technologies

Material	Propagation Loss
Crystalline Silicon	1.7 dB/cm [Xia et al. 2007]

- Crystalline Silicon
  - Best electrical and optical properties
  - Unable to deposit

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Polycrystalline Silicon	6.45 dB/cm [Fang et al. 2008]

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- Polycrystalline Silicon
  - Can deposit
  - Very lossy

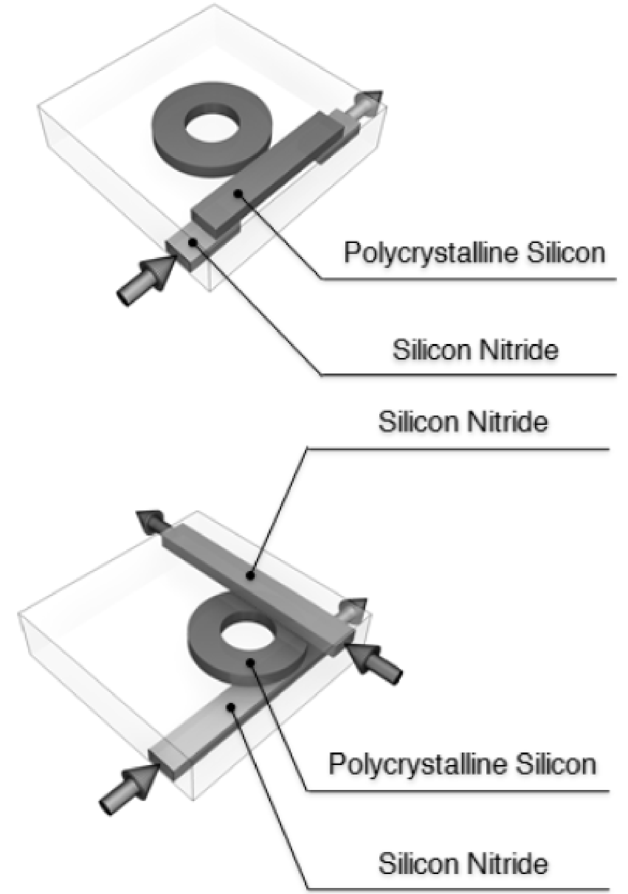
Silicon Photonics Technologies

Material	Propagation Loss
Crystalline Silicon	1.7 dB/cm [Xia et al. 2007]
Polycrystalline Silicon	6.45 dB/cm [Fang et al. 2008]
Silicon Nitride	0.1 dB/cm [Shaw et al. 2005] [Gondarenko et al. 2009]

- Crystalline Silicon
  - Best electrical and optical properties
  - Unable to deposit
- Polycrystalline Silicon
  - Can deposit
  - Very lossy
- Silicon Nitride
  - Very low loss
  - Can deposit
  - Not useful active devices

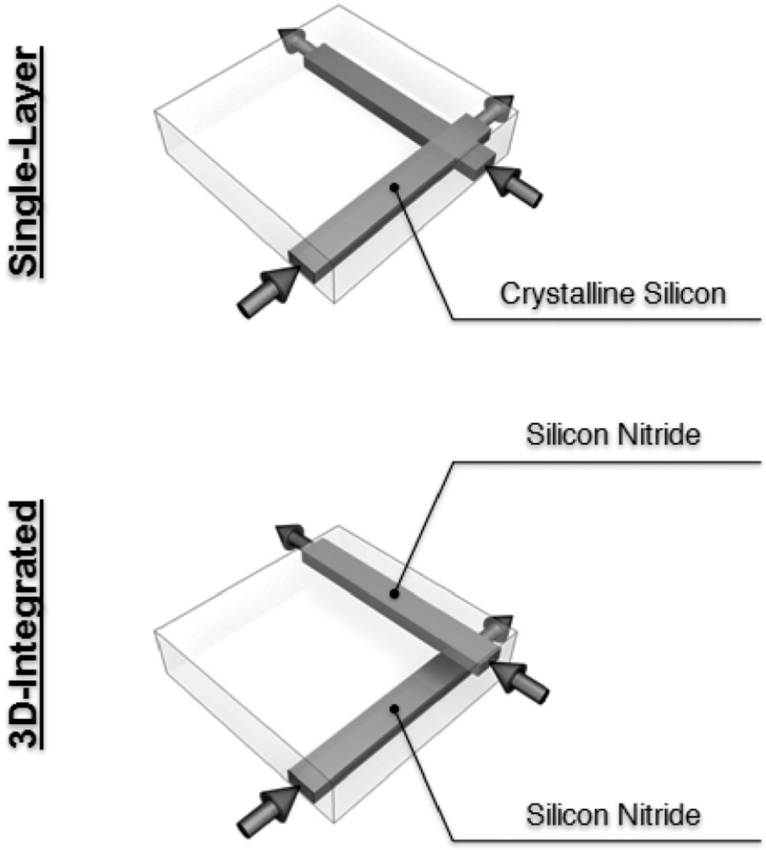
Poly-Si / SiN Combination approach

- We can use silicon nitride and polycrystalline silicon in combination
  - SiN for non-active wave guides
  - Poly-Si for active devices (e.g. ring-resonator based switch)



Designs for a layered modulator and switch

Poly-Si / SiN Combination approach



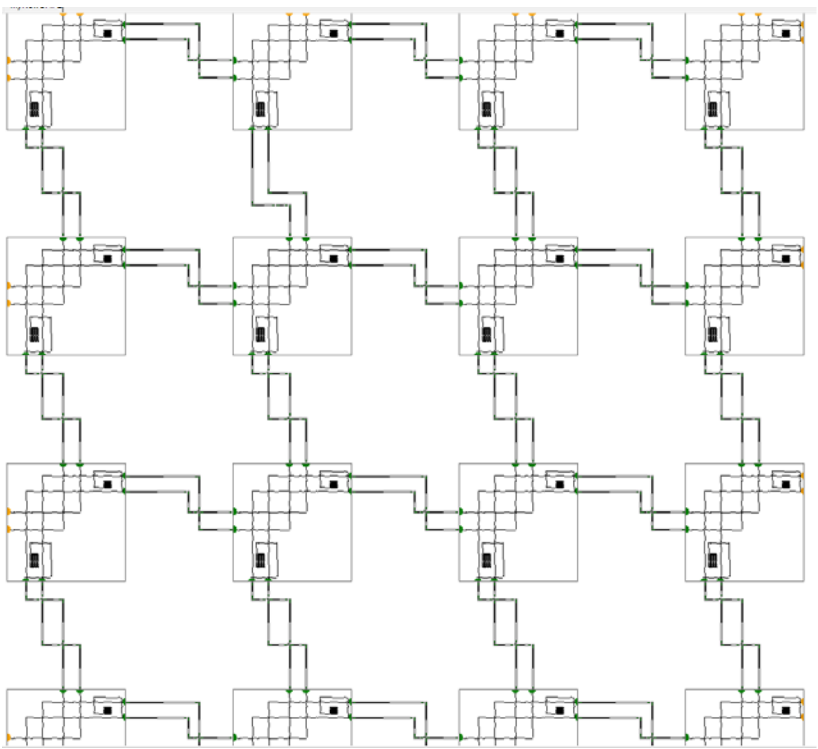
Waveguide crossings eliminated

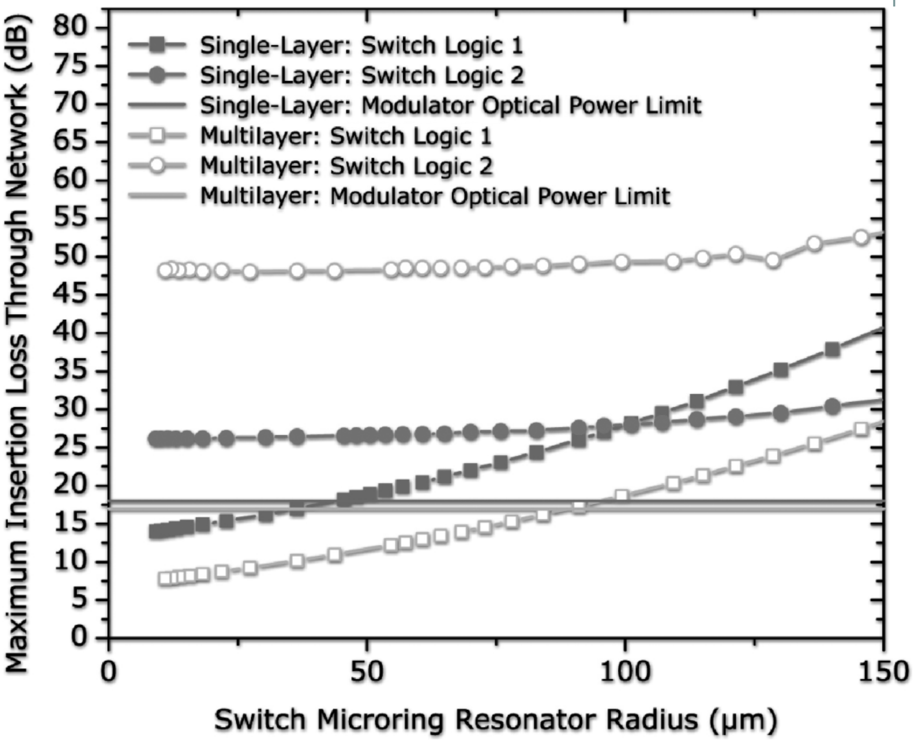
- Insertion loss, crosstalk both incurred heavily in waveguide crossings

However, .1 dB insertion loss per vertical coupling [Sun et al. 2008]

Insertion Loss Analysis

- Worst-case insertion loss for a photonic mesh





[Biberman et al. 2011]

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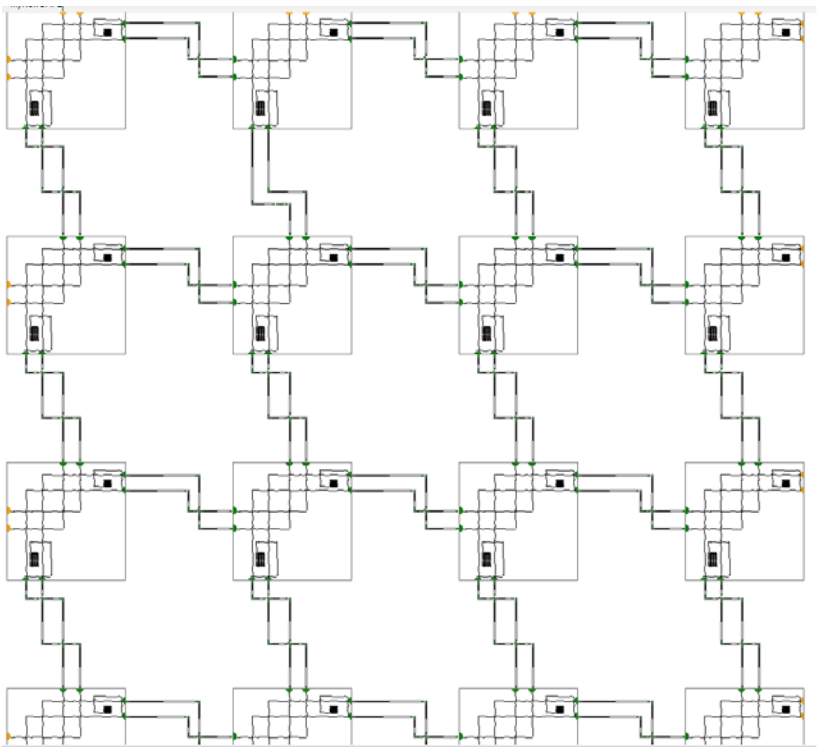
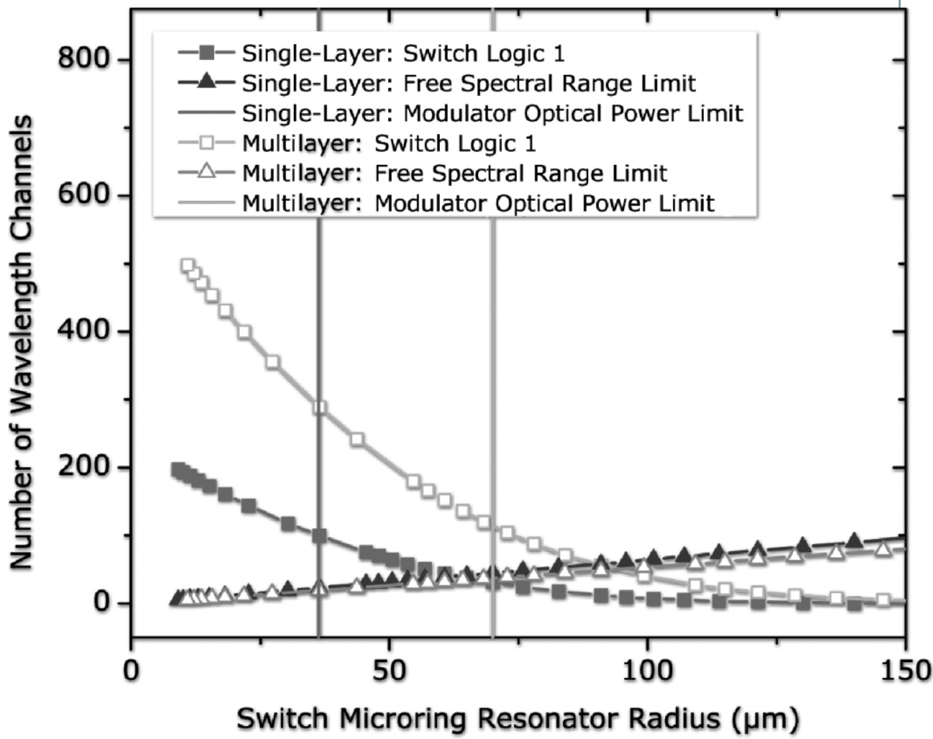
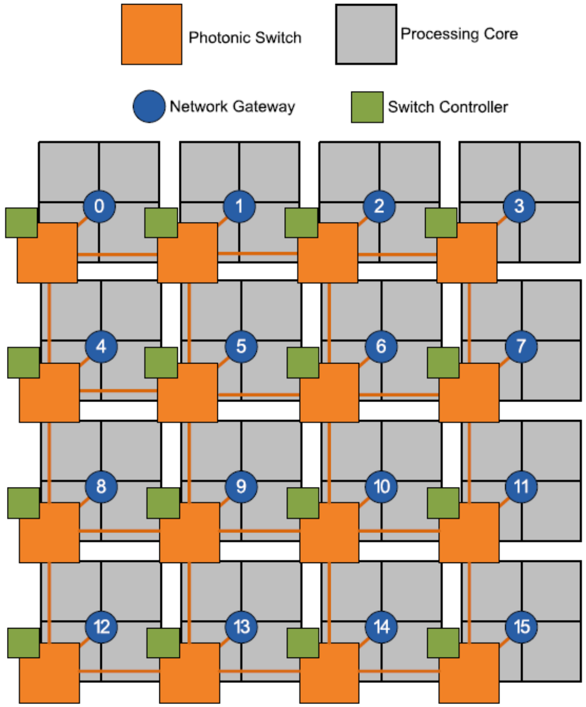


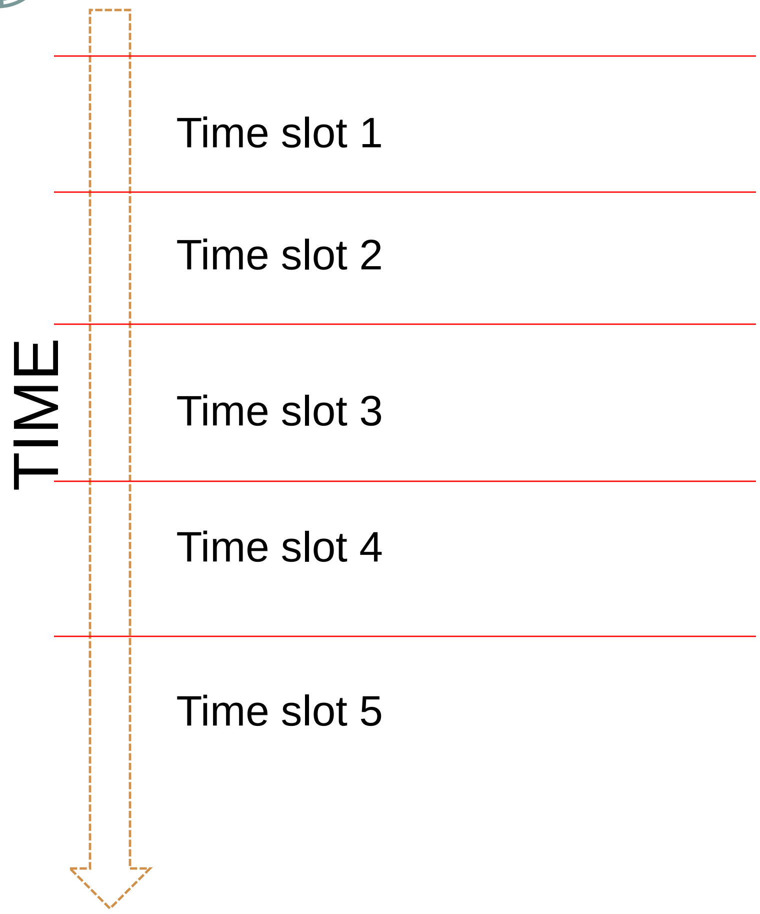


[Biberman et al. 2011]

Photonic TDM NoC Architecture

- Mesh topology
- No electronic links, other than TDM clock distribution





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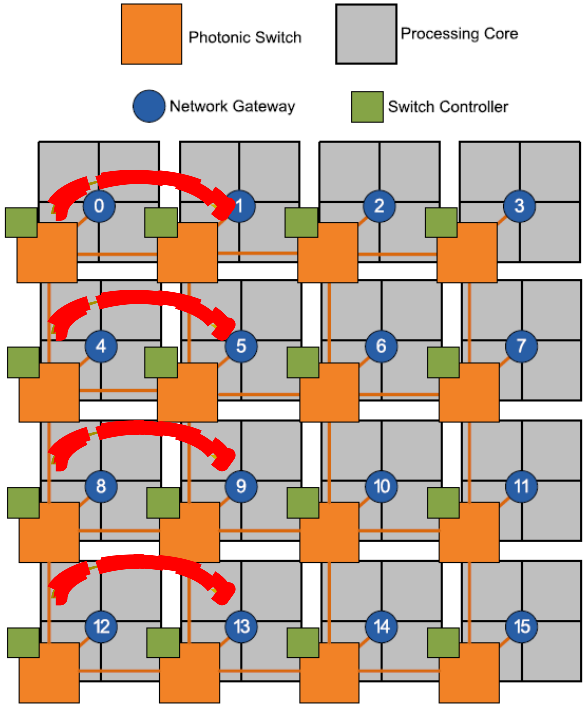

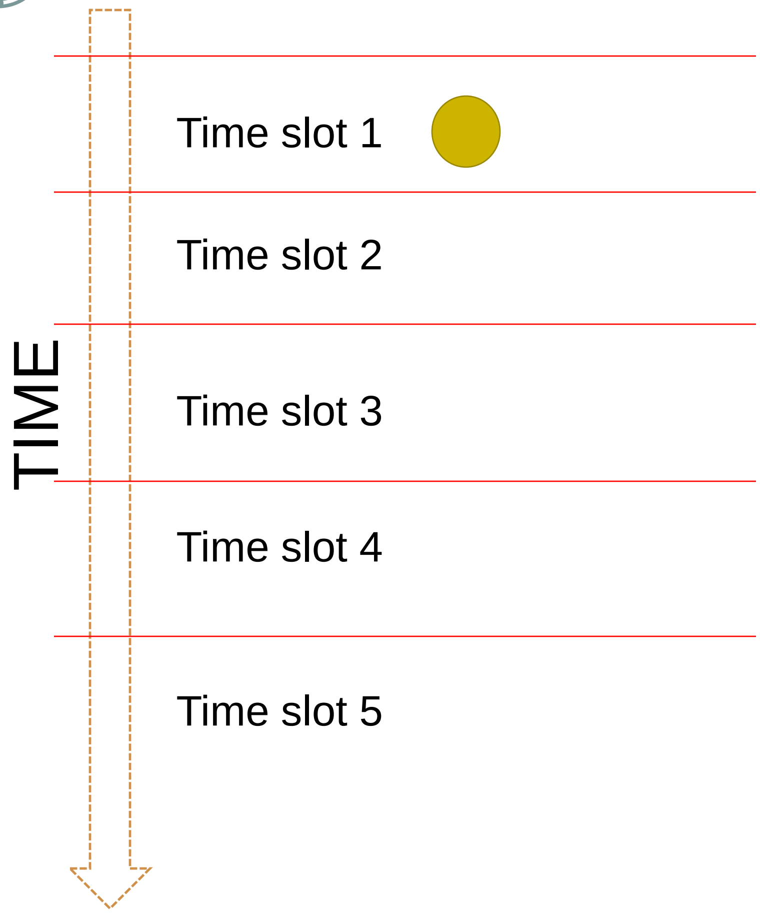

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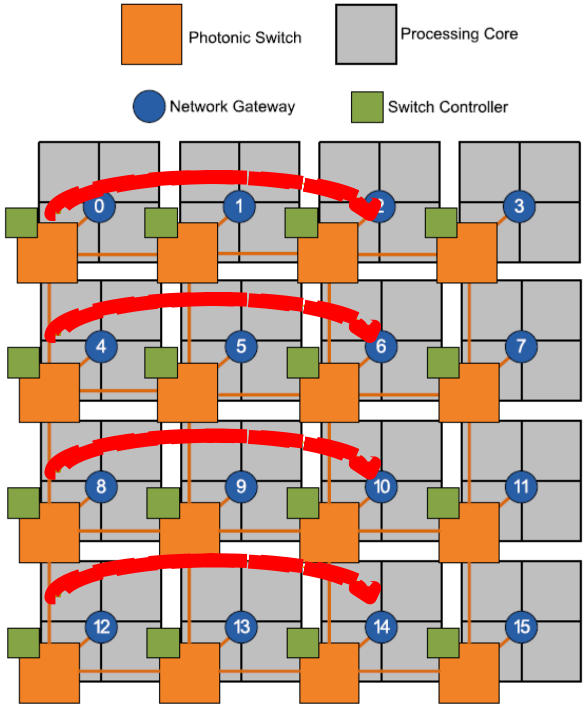

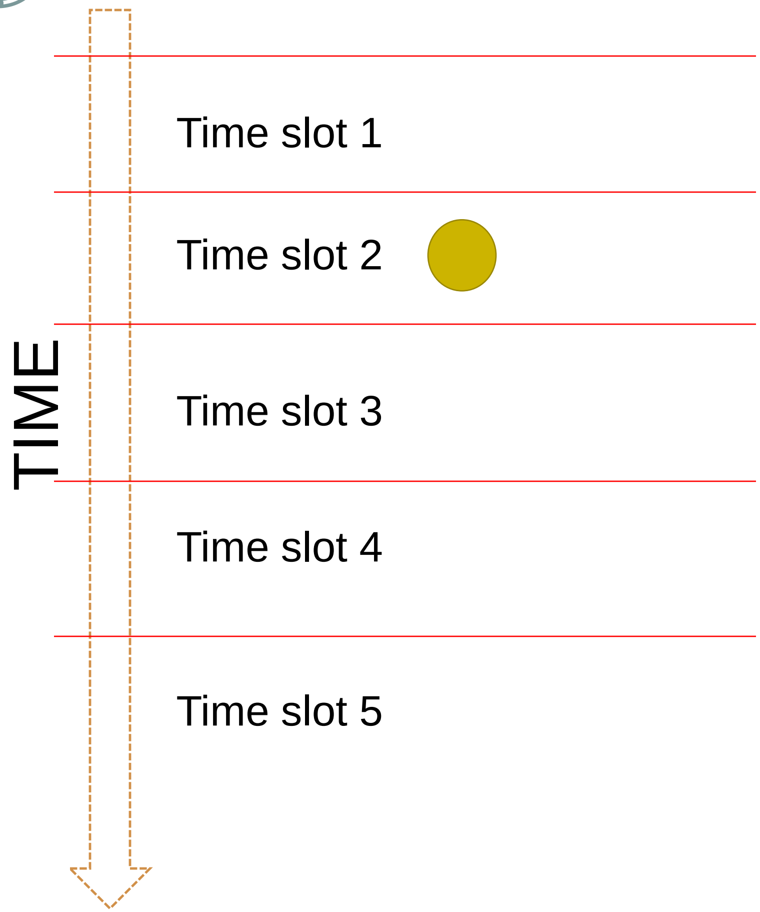

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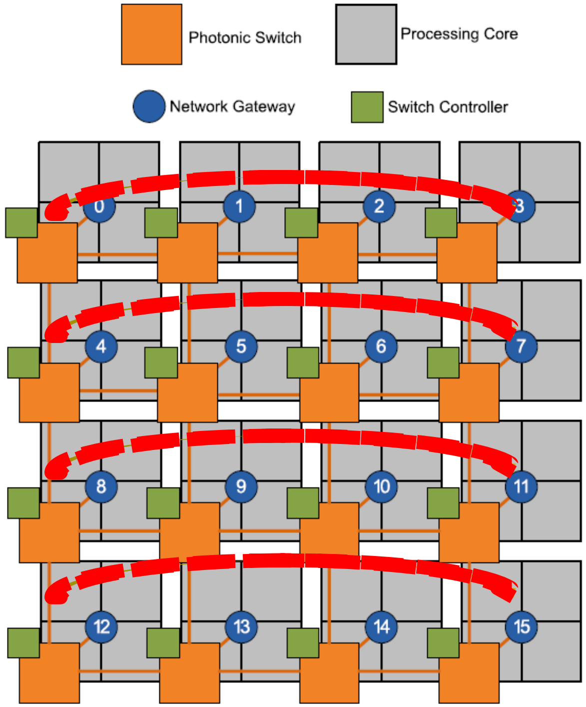

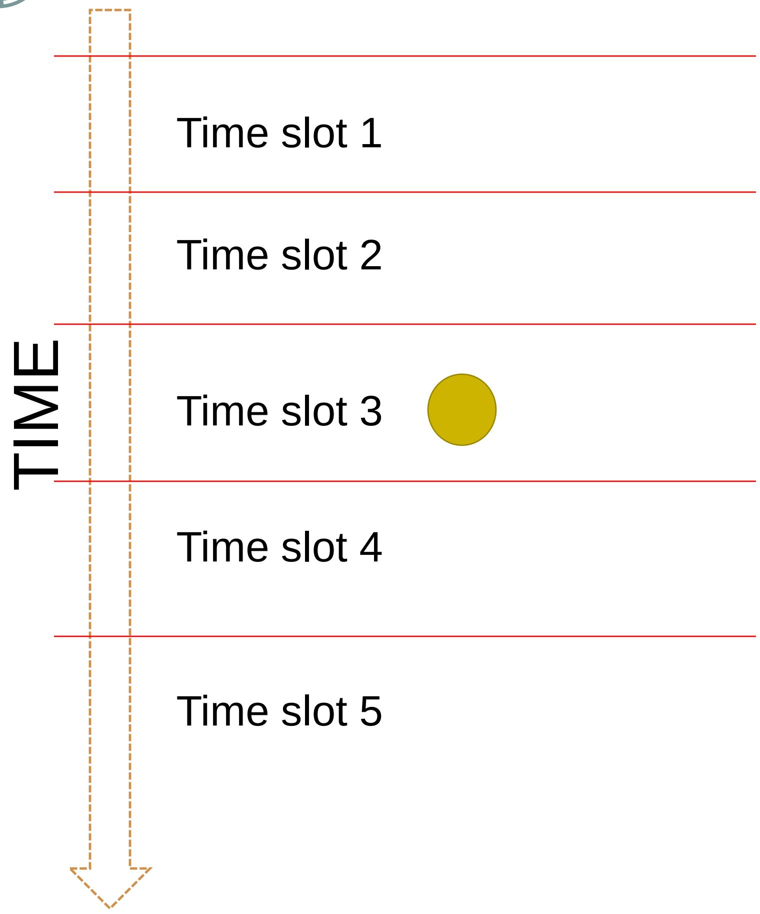

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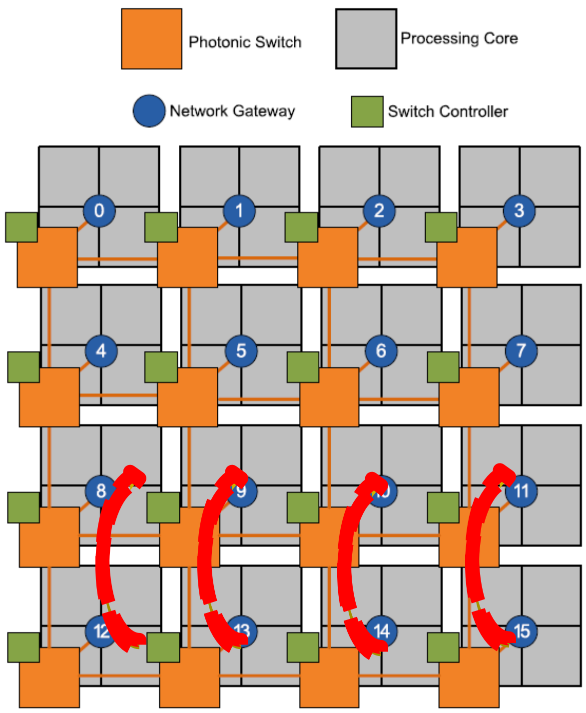

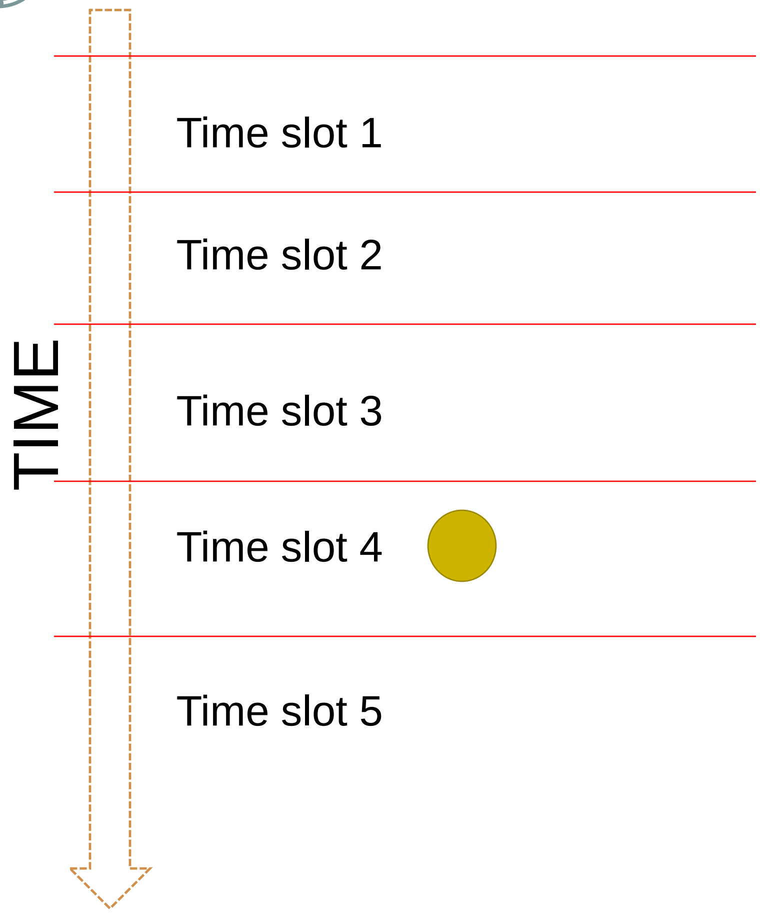

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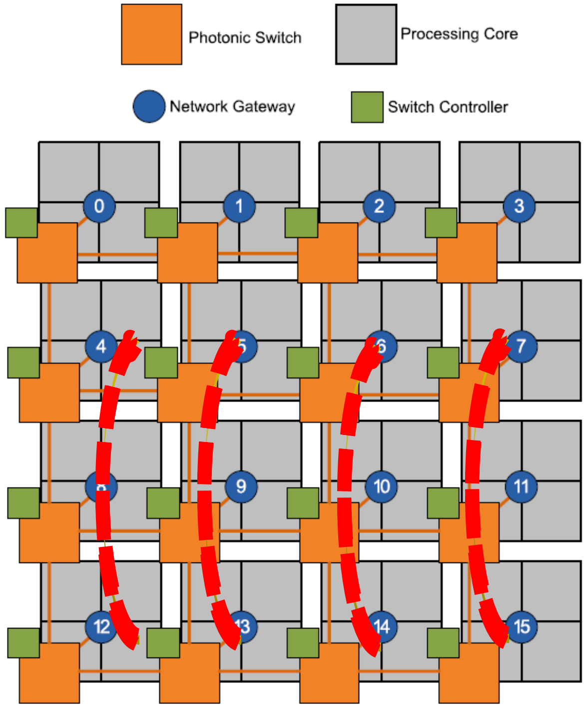
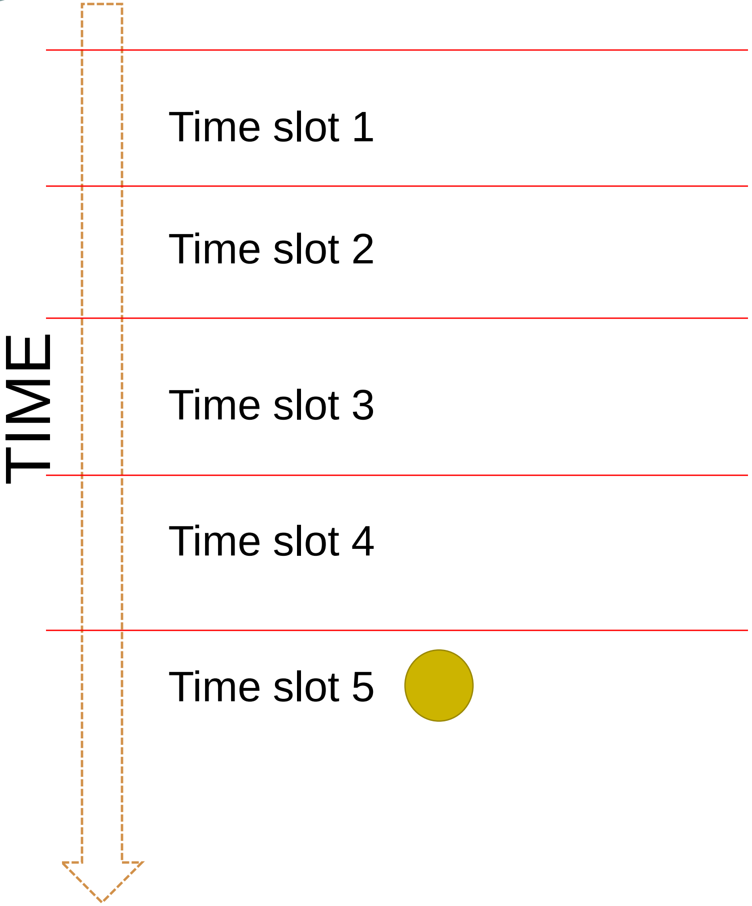
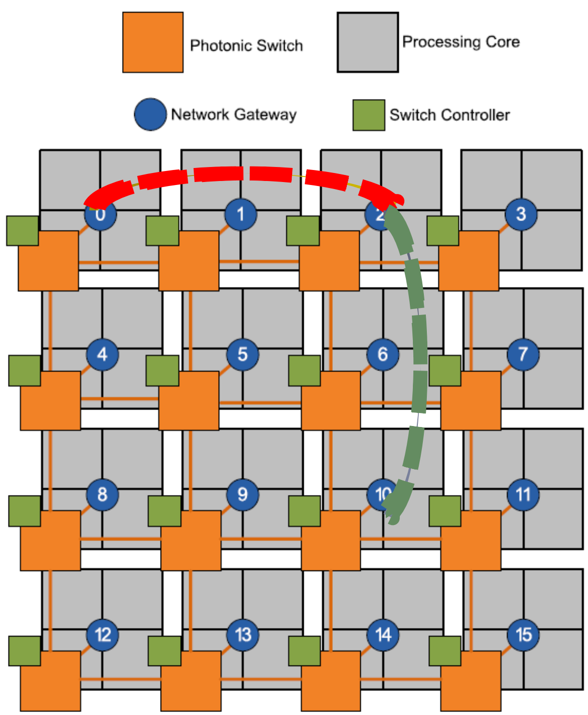
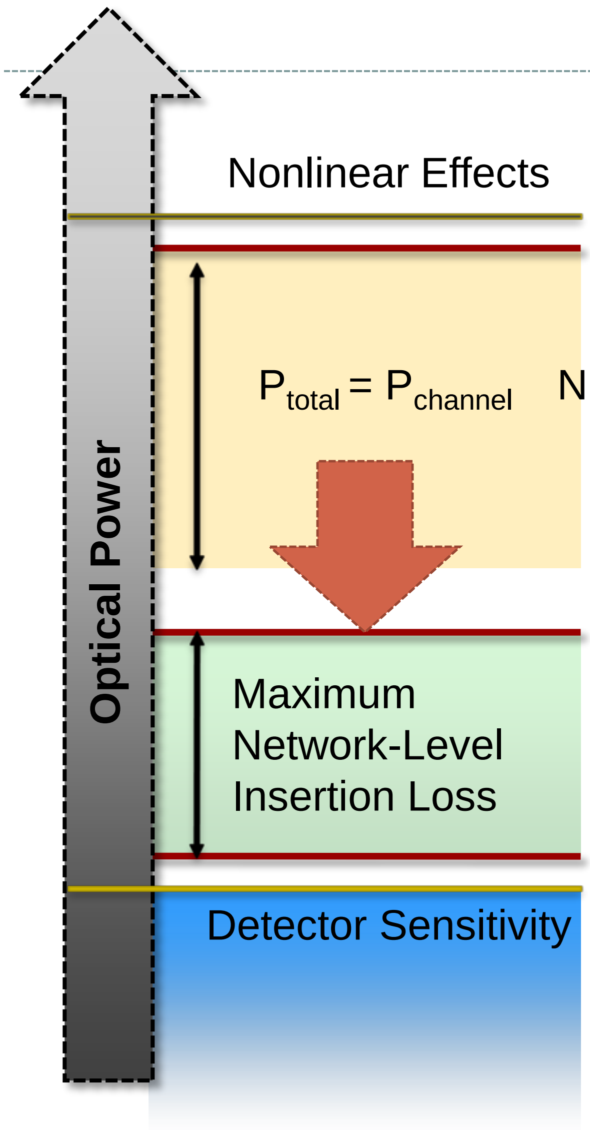




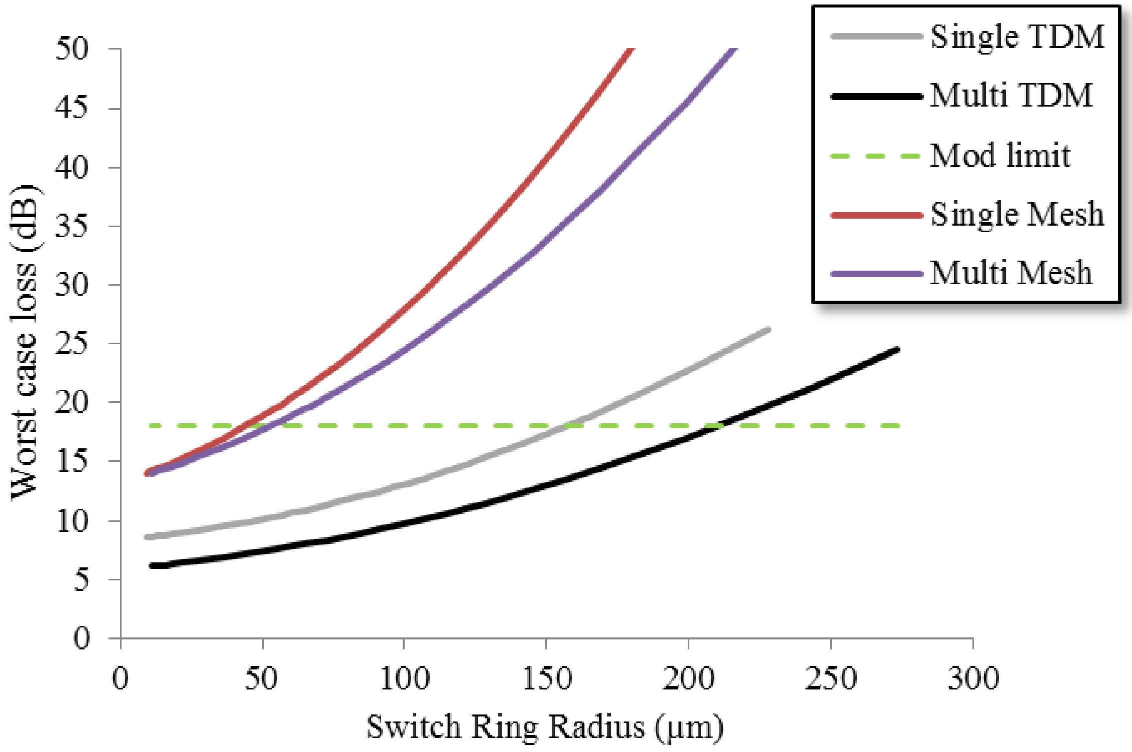
X-Y Buffering

- Mesh topology
- No electronic links, other than TDM clock distribution



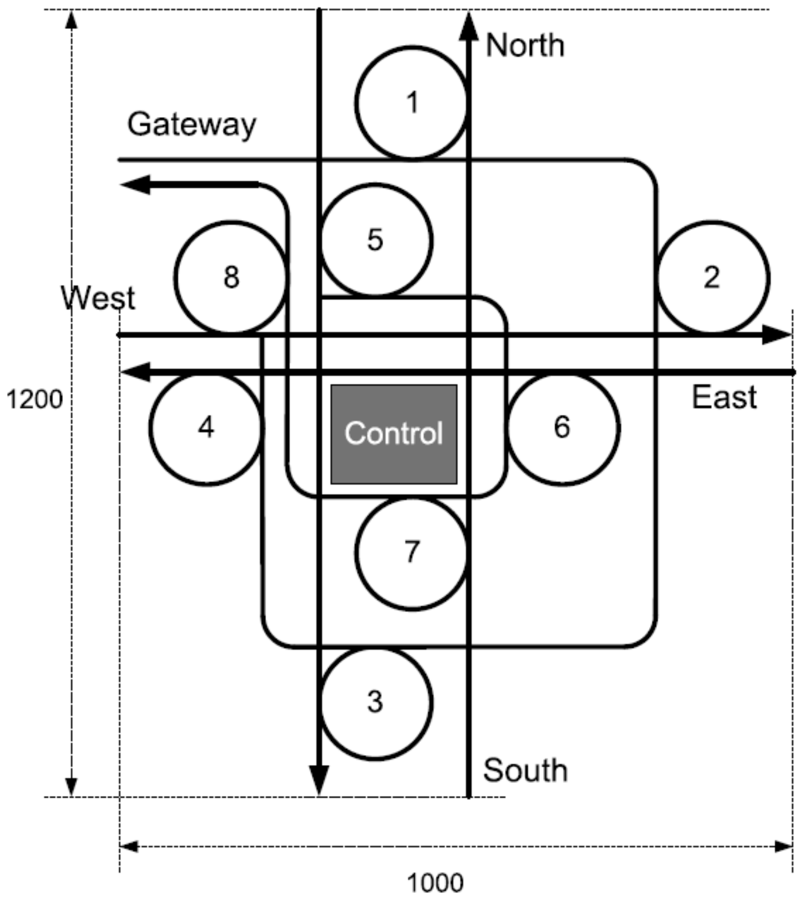


Photonic TDM vs. Photonic Circuit-Switched Insertion Loss

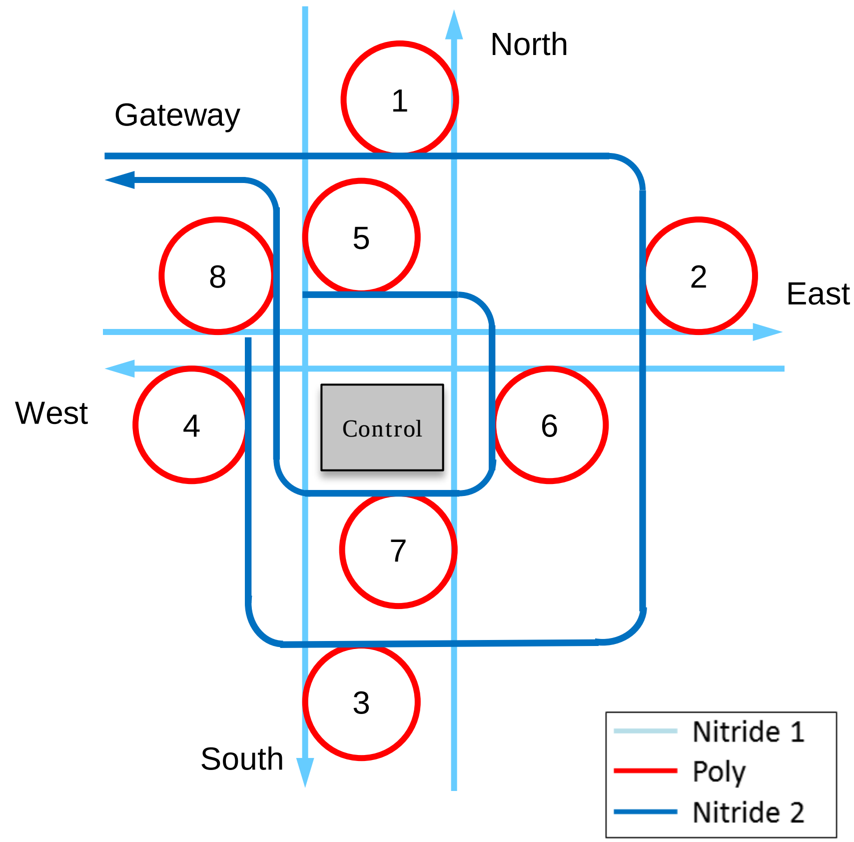


Single-Layer Switch vs. Multi-layer Switch

Single-layer TDM Switch

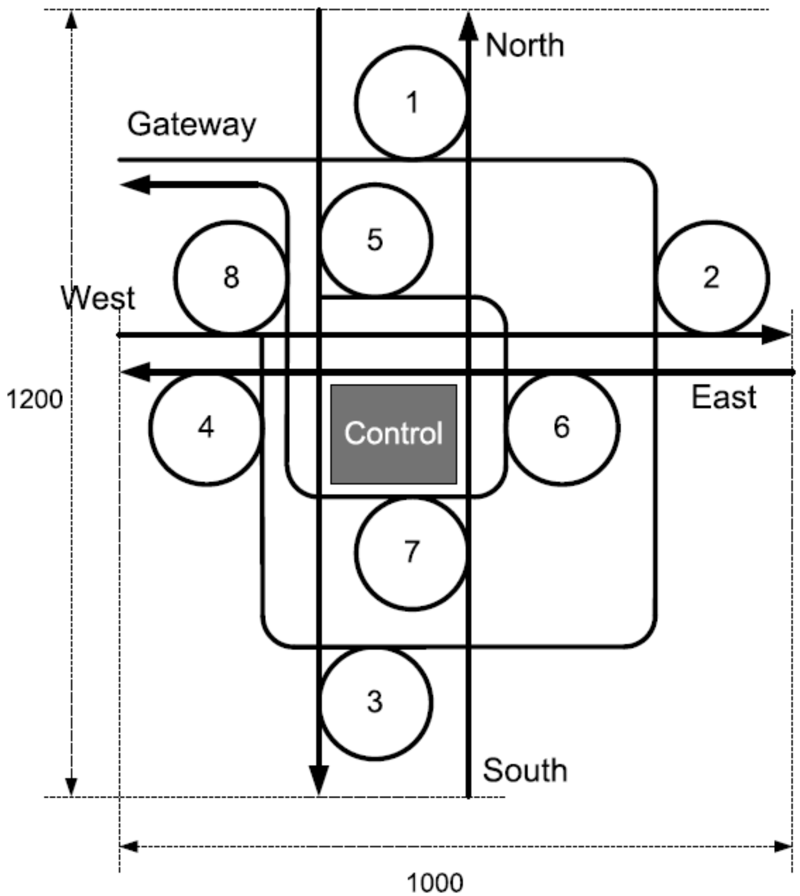


Multi-layer TDM Switch



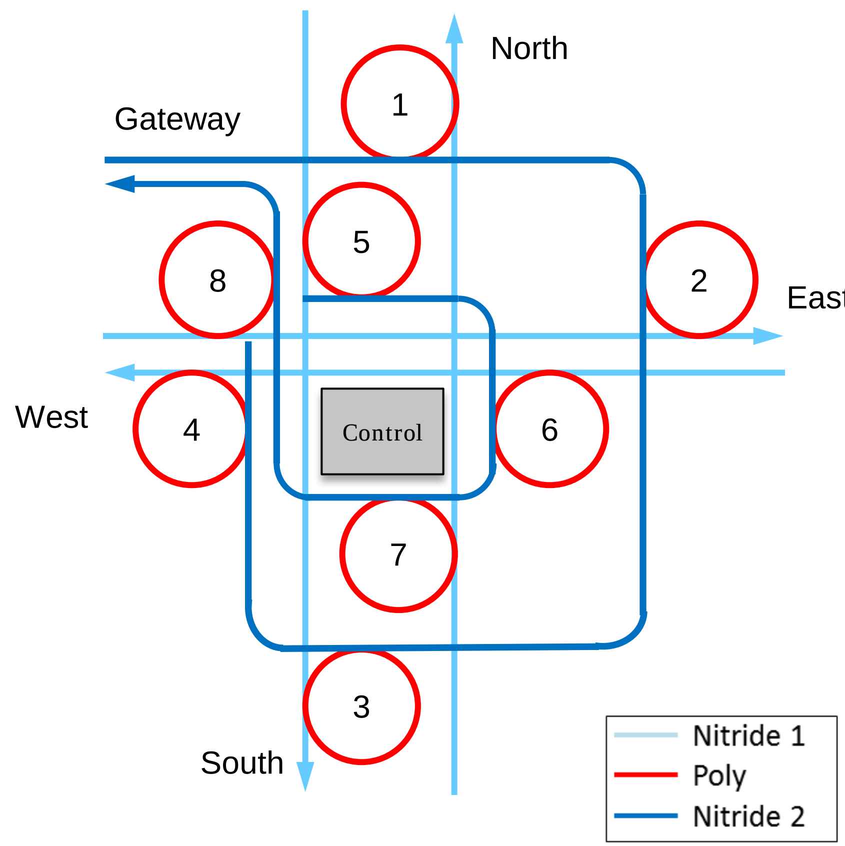
Single-Layer Switch vs. Multi-layer Switch

Single-layer TDM Switch



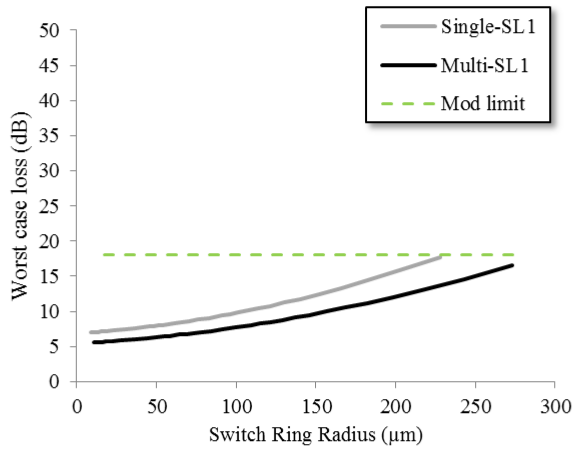
18 crossings

Multi-layer TDM Switch

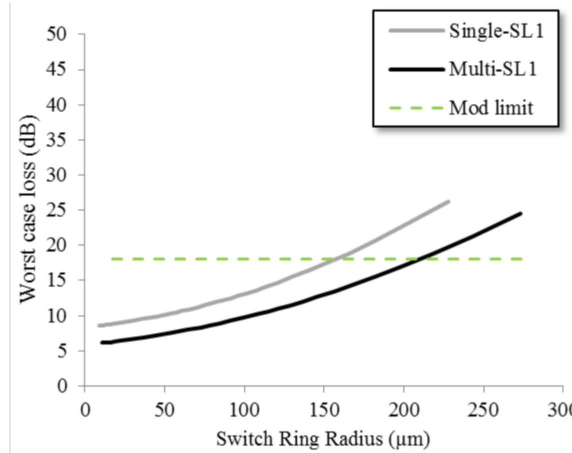


4 crossings

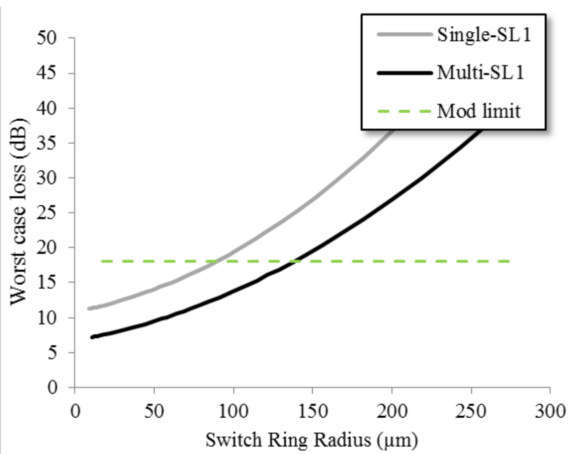
TDM Network Insertion Loss Analysis



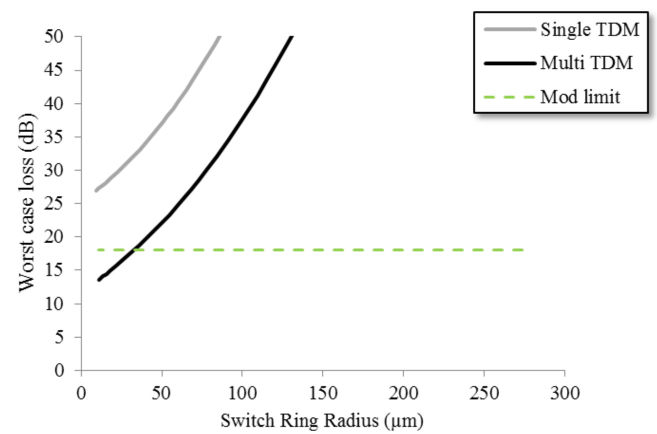
4x4 Network



8x8 Network

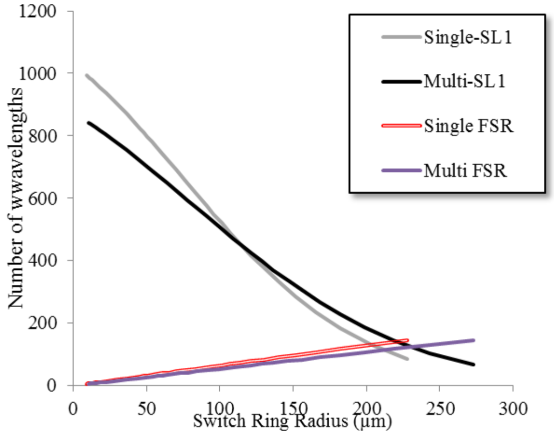


16x16 Network

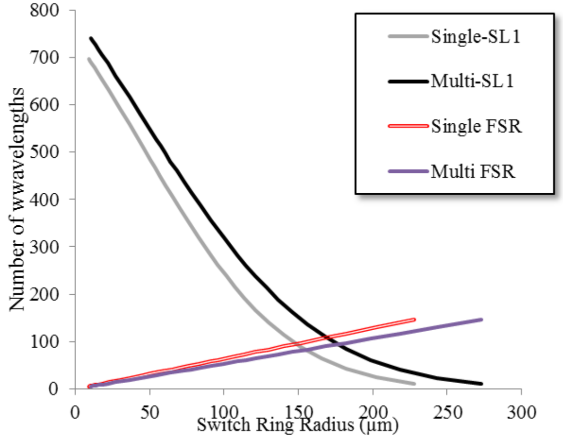


64x64 Network

Maximum Bandwidth (# of Wavelengths)



4x4 Network



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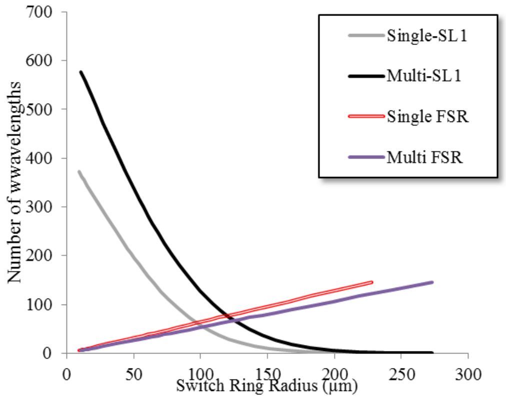

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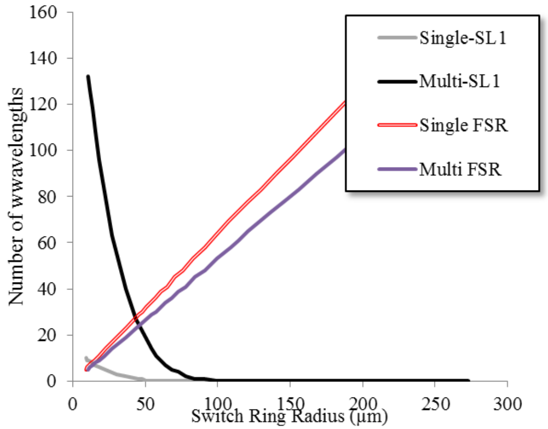
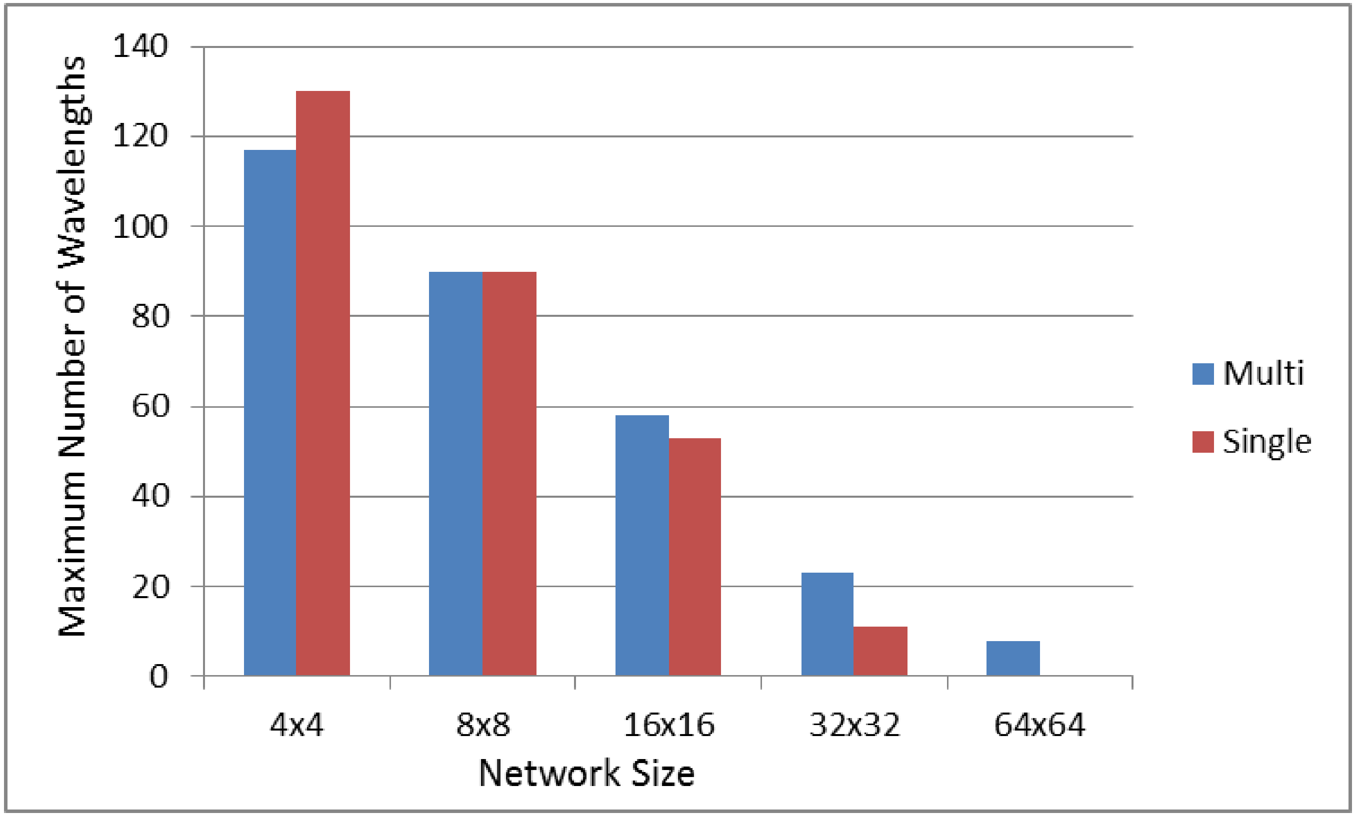


64x64 Network

Summary of Results



Conclusions

- Poly-Silicon and Silicon Nitride in conjunction are a good choice of materials for photonic interconnection networks
  - Low-loss
  - = more wavelengths = higher bandwidth
- We've shown that our best network, when at large scale, can be improved with a multi-layer implementation
- Future work: We expect the elimination of waveguide crossings to significantly reduce crosstalk across a wide variety of network architectures