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Rack-Scale Optical Network for High Performance Computing Systems

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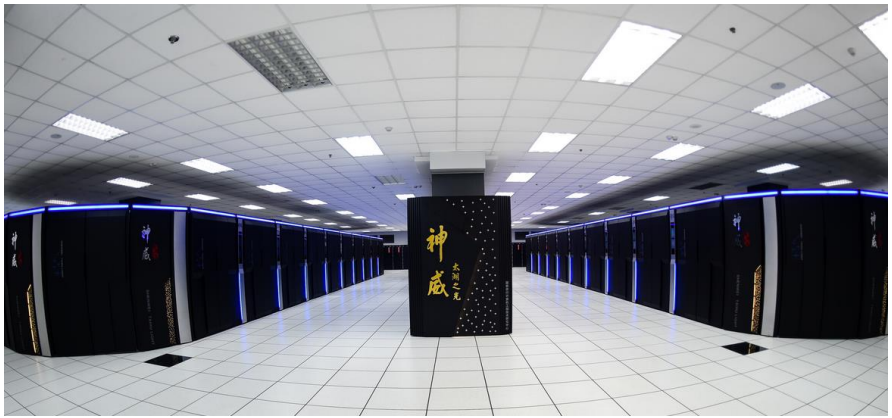
Outline

- Introduction
- Rack-scale inter/intra-chip optical network (RSON)
- Evaluation and analysis
- Conclusion

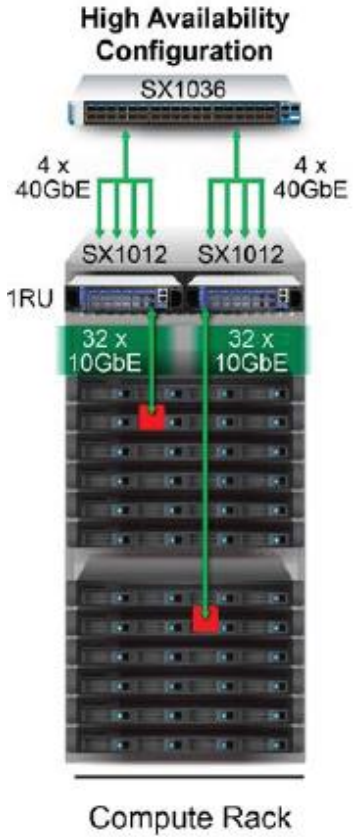
Large scale high performance computing systems

- Scientific computing, big data, and AI applications
  - Weather prediction, SNS, deep neural networks…
- HPC and cloud computing
  - Sunway TianhuLight with ~10M cores(1ST, Nov 2017)
- Exascale system requirements:
  - Total computing power: ExaFlop/s
  - Energy efficiency: 50 GFLOPS/W
  - Interconnection side: ~20 pJ/bit



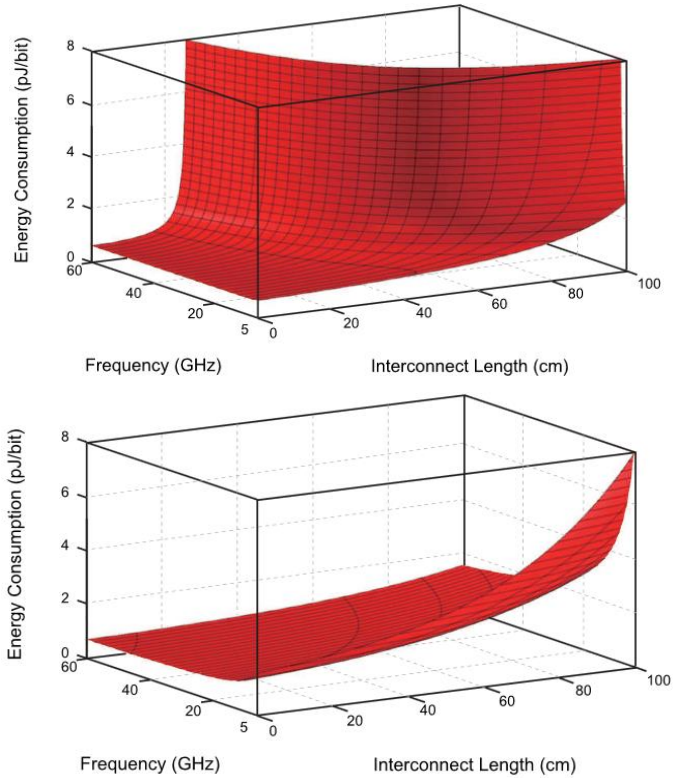
Rack-scale computing system

- **Rack-scale computing system:**
  - **Merged scale-up and scale-out model**
  - **Close-coupled computing and communication**
  - **Widely employed standardized structure: HP Moonshot, Intel RSA**
- **Intra-rack communication is becoming the bottleneck**
  - **~80% traffic stays within the rack in cloud computing**
  - **Efficient and low latency access to intra-rack resource**
  - **Dominant power in system interconnection**



Optical interconnection for rack/large scale systems

- **Available solutions**
  - **Ethernet, Fibre Channel, InfiniBand…**
  - **Electrical Top-of-Rack (ToR) switch**
  - **ENoC for multicore chips**
- **Optical interconnection to address the electrical link challenges**
  - **High energy consumption**
  - **Limited data rate**
  - **Chip pin counts**
  - **High latency**



[Z. Wang et al, 2015

Related works on optical interconnected rack

- **Inter/intra-chip optical network:**
  - **Hybrid E/O NoC** [N. Kirman et al 2006; Y. Pan et al, 2010; Y. Ye et al, 2012; X. Wu et al, 2014]
  - **All-optical NoC** [S. Koohi et al, 2012;Y. Ye et al, 2013; S. Bartolini et al, 2013; M. Browning et al, 2013]
  - **Inter and intra-chip optical network**[X. Wu et al, 2013; X. Wu et al, 2015]
- **Rack-scale optical network**[J. Kim et al, 2009; S. Liu et al, 2014; J. Chen et al, 2015, V. Shrivastav et al, 2017]
  - **Optical switch and path control is oversimplified**
  - **Electrical intra-chip network**
- **The unified inter/intra-chip rack-scale optical network is not fully investigated!**
  - **Different traffic for on-chip and off-chip communication**
  - **Co-consider inter-chip and intra-chip network architectures**
  - **Detailed control for active switching**

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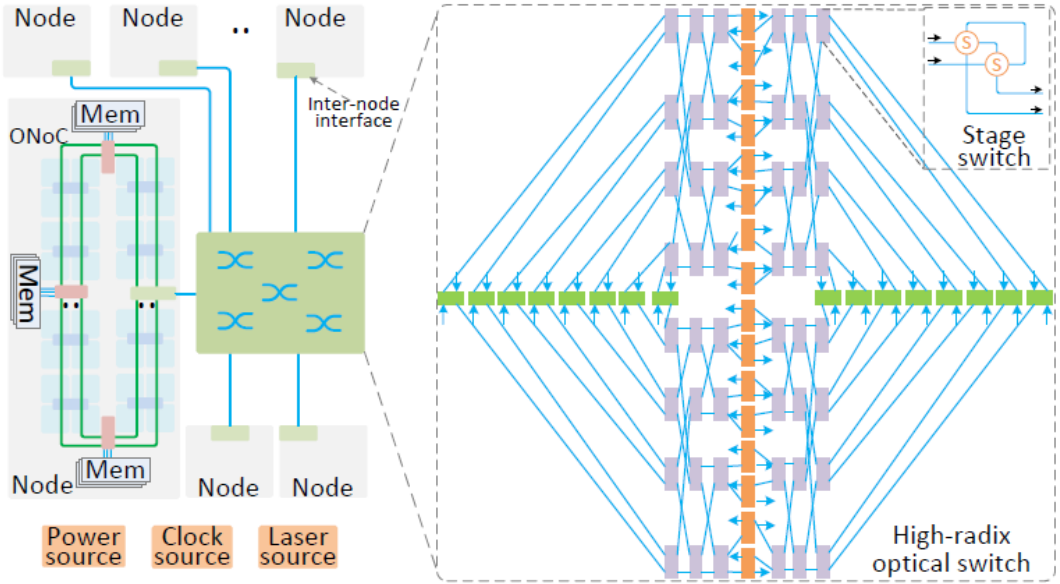
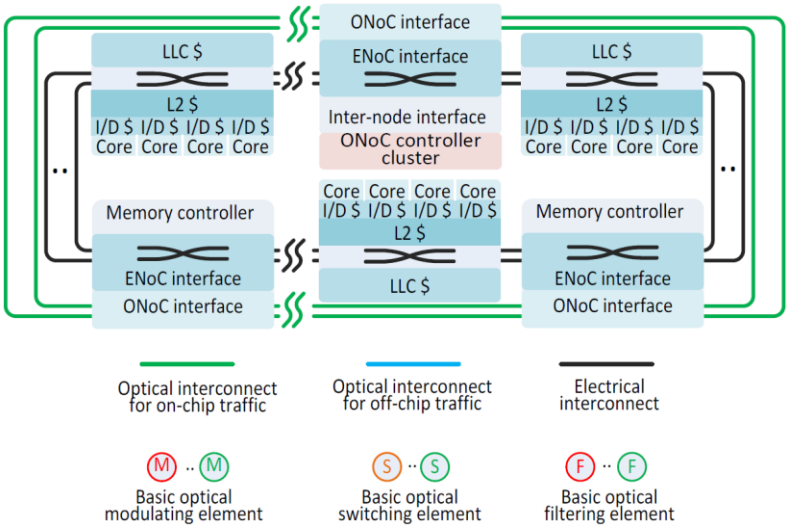
Rack-scale optical network architecture overview

- **High-radix integrated optical switch fabric**
- **Unified inter/intra-chip optical interconnect**
- **Hybrid electrical/optical NoC**
- **Multi-domain circuit switching**



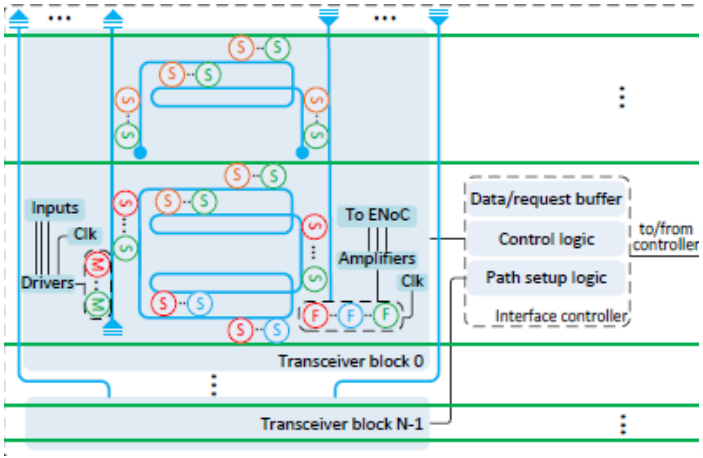
Hybrid E/O server node network architecture

- **Sufficient computing power and memory space**
  - **Multiple core clusters: four cores with I/D $**
  - **Multiple memory controllers**
- **Hybrid and complementary ENoC and ONoC**
  - **ENoC for legacy connection of on-chip resources**
  - **ONoC connecting memory controllers and inter-node interface**
  - **High-bandwidth bypass for memory access between on-chip and off-chip domains**



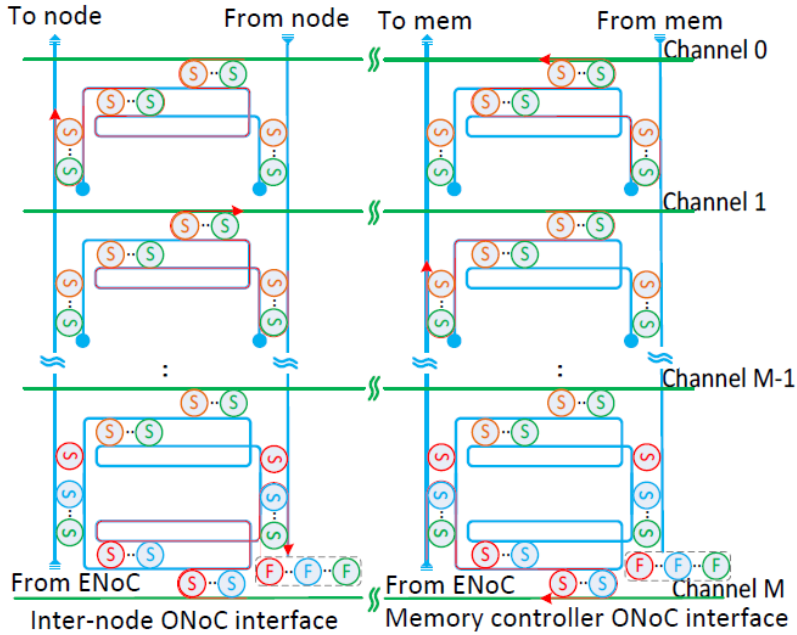
Optical inter-node interface

- Efficient interaction between on-chip and off-chip networks
  - Similar architecture as ONoC interface
  - Hold ONoC controller to control channels
  - Handle all path requests to the optical switch
- Essential to break the performance gap between intra-chip and inter-chip domain
- Avoiding the power hungry E/O/E conversion



Optical transceiver block

- **Power efficient E/O/E conversion**
  - **Shared Tx & Rx among different data channels**
  - **Optical weaving serdes**
- **Merged on-chip and off-chip domain**
  - **Bidirectional switching between horizontal and vertical links**
- **Efficient control signals exchanging**
  - **Unique wavelength for each ONoC interface via channel M**

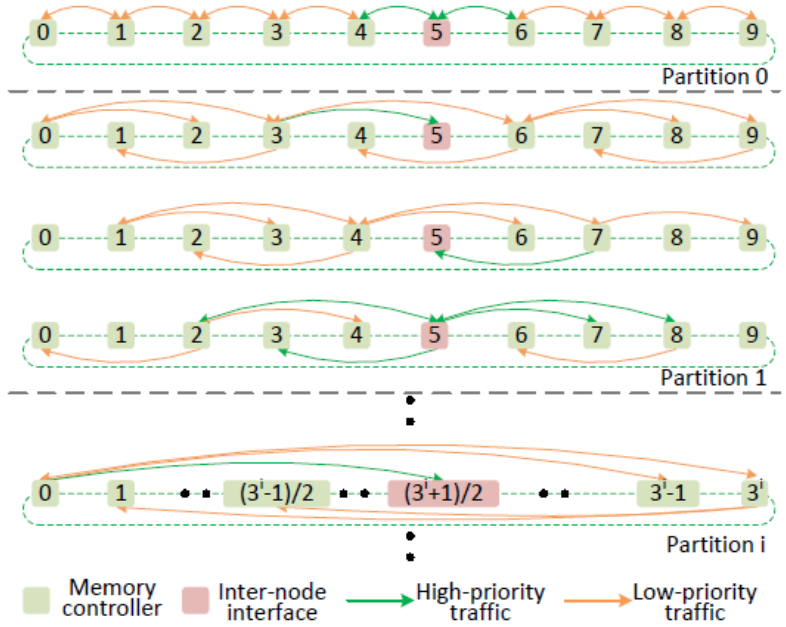


Optical switch control

- **Requiring fast control signaling between server node and switch**
  - **Separate control and data links**
  - **Internal forwarding request/grant**
- **Fully desynchronized round-robin arbitration**
  - **Reduce the synchronized contention for the same output port/path**
  - **Increase the path reservation success ratio**
- **Efficient implementation of the 64x64 arbiter**
  - **Power: ~250 mW**
  - **Area: ~1.07 mm^2**

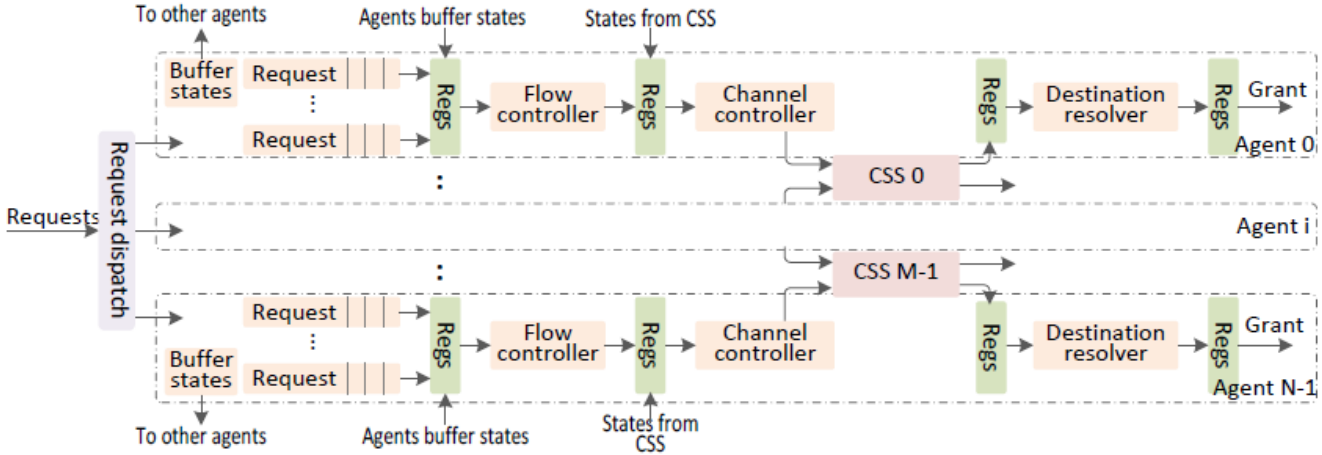
ONoC channel partition

- **Reduce the arbitration overhead**
  - **Divide channels into partitions**
  - **Scalable and low arbitration complexity, O(1)**
- **Fulfill different traffic demand**
  - **Dynamically allocate data channels to each partitions**
- **Different priority for specific traffic**



Control implementation

- **Reduce control system latency and increase processing efficiency**
  - **Pipelined structure**
  - **parallel for each interface agent and channel section solver**
- **Low power overhead: ~61 mW for 16 interfaces**



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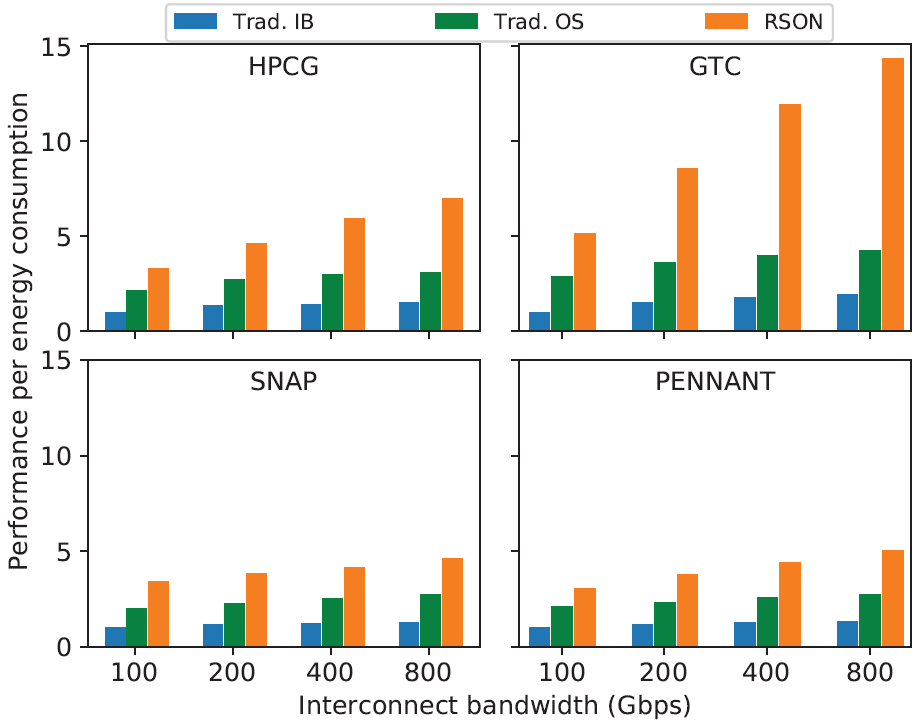
Simulation environment and setup

- JADE full-system simulator
- InfiniBand and optical switch for comparison
- APEX benchmark
- McPAT and CACTI for electrical power evaluation
- 64-node, bandwidth from 100 to 800Gbps: 25 Gbps/wavelength

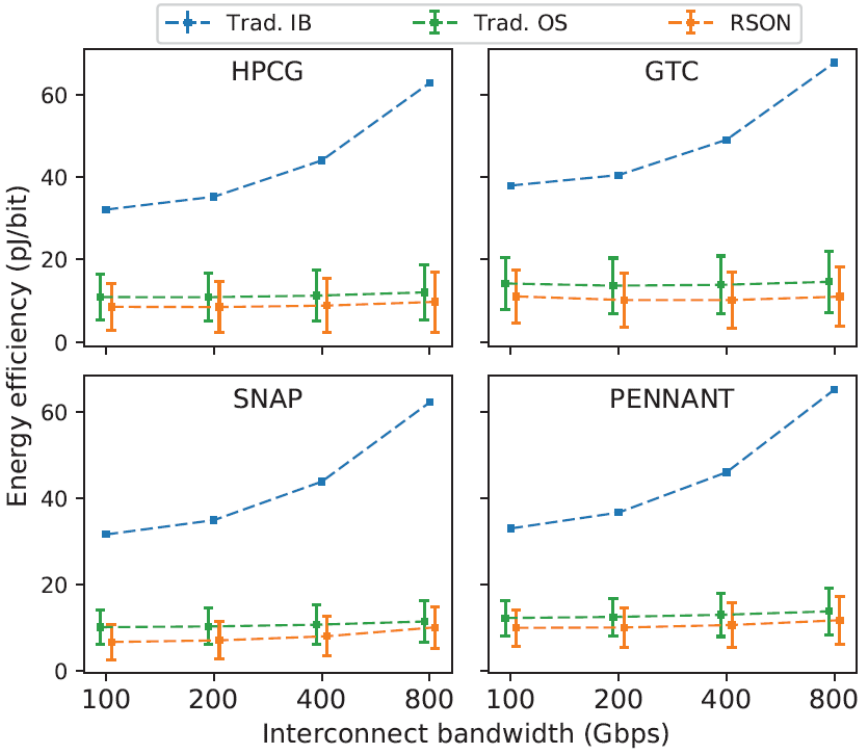
Item	Configuration
Core cluster	8, 4 cores/cluster
L1 I/D $	64KB/core, private
L2 $	512KB/cluster, shared
LLC	2.5MB/slice
Coherence protocol	Directory based MOSI
Electrical link	128-bit width/direction
Memory bandwidth	480GB/s/port
Memory capacity	16GB/port

Performance per energy consumption

- **RSON achieves most performance, 6.8X at best**
- **High bandwidth interconnect benefits RSON more**



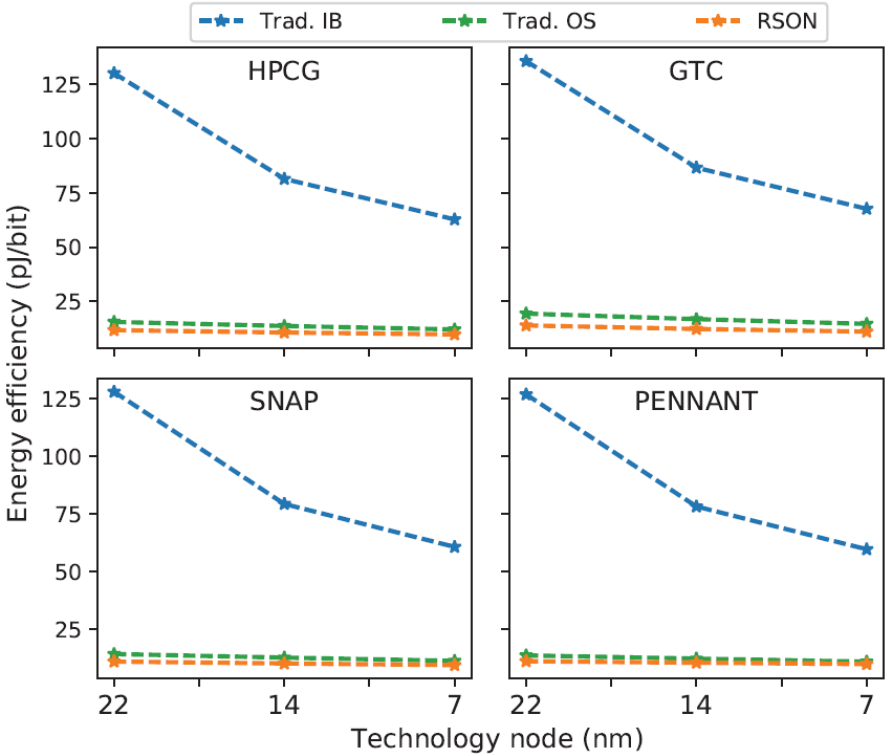
Interconnection energy efficiency



Item	Value
Laser efficiency	0.33 [48, 49]
MR insertion loss	1∼1.8 dB
MR passing loss	0.06∼0.3 dB
Edge coupling loss	1∼1.5 dB
Waveguide crossing loss	0.3∼0.8 dB
Waveguide propagation loss	0.8∼1.3 dB/cm
Photodetector sensitivity	-15 ∼ -20 dBm

Energy efficiency vs. technology node

- Goes down for all three designs
- Better improvement for Trad. IB
  - Still higher than RSON
  - Beyond the power budget on exascale



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Conclusion

- **Propose the inter/intra-chip rack-scale optical network**
  - **The architectural design of inter-chip and intra-chip optical network**
- **Efficient channel control for optical switch and ONoC**
- **Systematic evaluation on RSON**
  - **Promising solution for energy efficient rack-scale high performance computing system**

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Q&A