

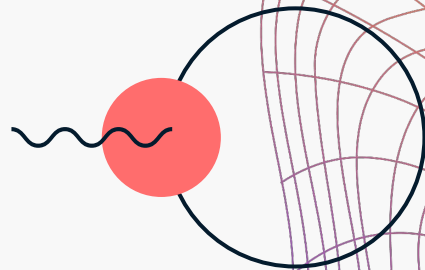


CNSS AUTH

Optical Switching in Data Centers

Google's Journey from Jupiter to Apollo

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AEM 180

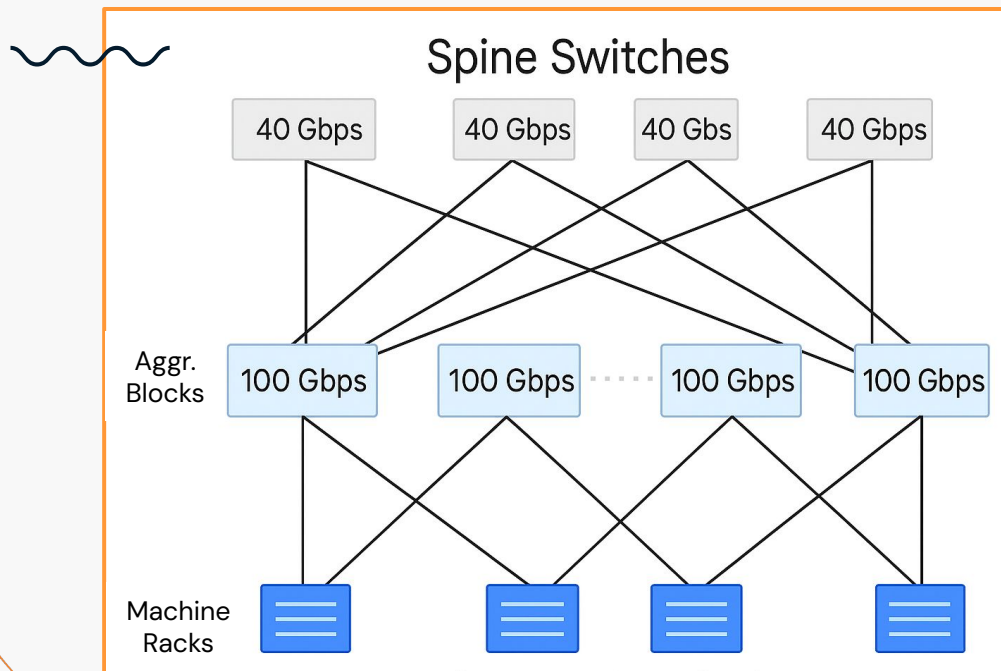


The Role of Networking in Modern Data Centers

- Cloud services and ML workloads demand scalable, high-performance networks.
- Traditional networks rely on Clos topology with electrical packet switches.
- Emerging trend: optical switching for higher bandwidth, lower cost, and better scalability.

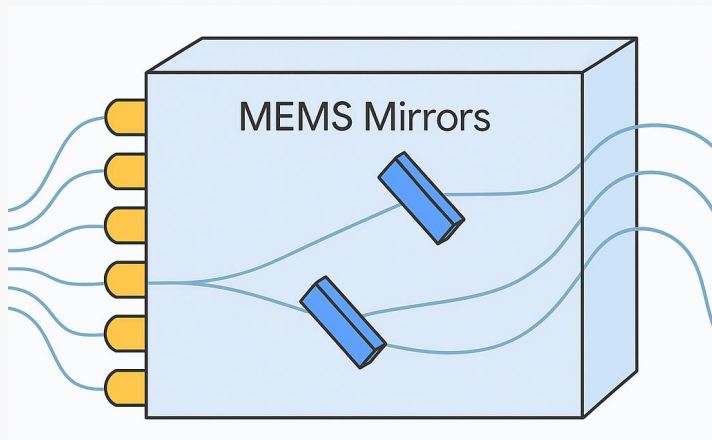


The Problem with Traditional Networks



- **Rigid Topology:** Clos topologies are difficult to scale and lack flexibility.
- **Bandwidth Bottlenecks:** Upgrading to higher-speed hardware is limited by existing spine switches.
- **Operational Disruption:** Rewiring and scaling require service downtime or complex planning.
- **Stranded Resources:** New compute/storage can't be fully utilized due to network constraints.

Optical Circuit Switches



What is an OCS?

- Uses MEMS mirrors to steer light directly between ports.
- Eliminates need for intermediate electrical switching.

Key Benefits

- **Protocol & Data-Rate Agnostic:** Supports multiple speeds/generations.
- **Energy Efficient:** No per-packet processing = much lower power.
- **Ultra Low Latency:** Pure optical path; minimal transmission delay.
- **Highly Scalable:** Easily supports evolving workloads like ML training.

Google's Jupiter Evolution



From Clos to Direct-Connect

Google transitioned from traditional Clos networks to direct-connect fabrics using OCS and SDN.

Key Achievements

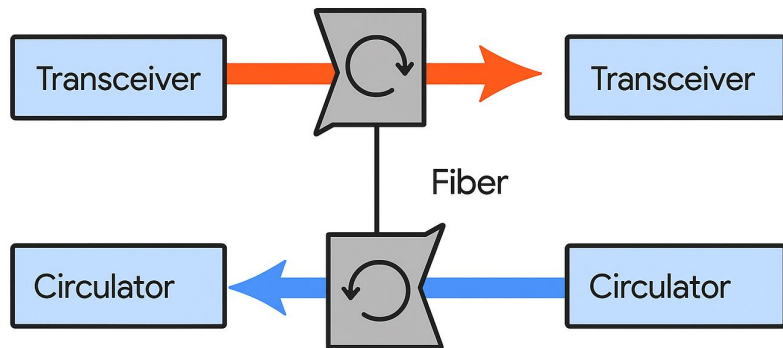
- 5× speed & capacity increase
- 30% cost savings, 40% lower power consumption
- Reducing flow completion by 10% and improving throughput by 30%

Dynamic Network Topology

MEMS-based OCS + SDN enables flexible, programmable routing and traffic engineering.

Technical Innovations in Jupiter

Circulators for Bidirectional Optical Links



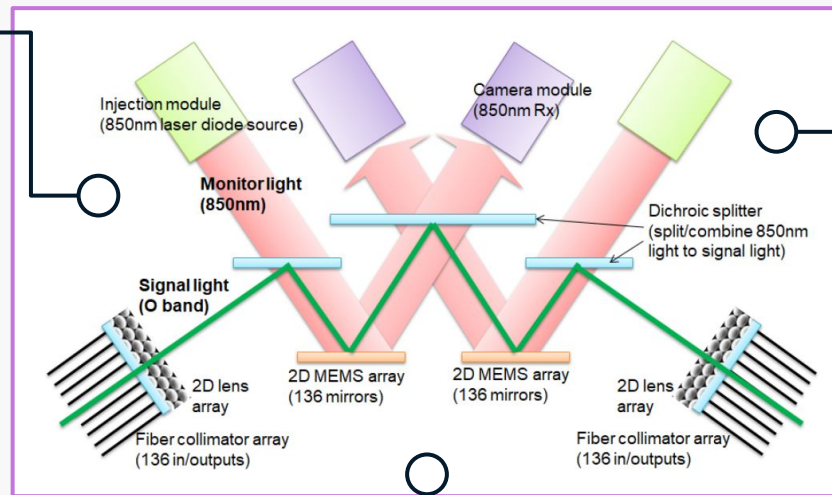
- **Direct-Connect Fabric (DCNI):** Bypasses traditional Clos layers with scalable optical interconnection.
- **Circulators for Bidirectional Traffic:** One fiber per direction → 50% fewer fibers & ports needed.
- **CWDM Transceivers:** Coarse Wavelength Division Multiplexing enables multi-gen compatibility.
- **Software-Defined Control (Orion):** SDN controller dynamically reconfigures topology and traffic flows.



Mission Apollo – Scaling Optical Switching

From Prototype to Production

First hyperscale deployment of Optical Circuit Switching in live data centers.



Palomar OCS Platform

- Custom-designed 3D MEMS switch
- 136×136 ports
- <2 dB insertion loss, ms-level switching time
- Fully field-replaceable and manufacturable at scale

Built for Scale & Longevity

- Designed for decade-long deployment
- Powers both general workloads and ML-focused networks

Apollo Network Architecture

Spine-Free Design

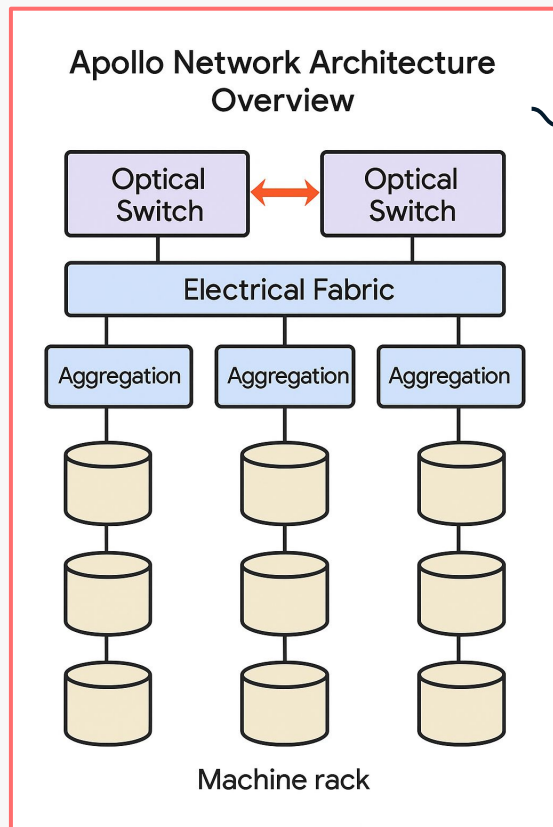
- Replaces traditional **spine switches** with **optical circuit switches**.
- Reduces **cost**, **power**, and **operational complexity**.

WDM + Circulators + OCS

Combines Wavelength Division Multiplexing, circulators, and OCS to form bidirectional, high-bandwidth optical links.

Built for Tech Evolution

Supports rapid expansion, interoperability between generations, and easy tech refresh.





Applications & Use Cases



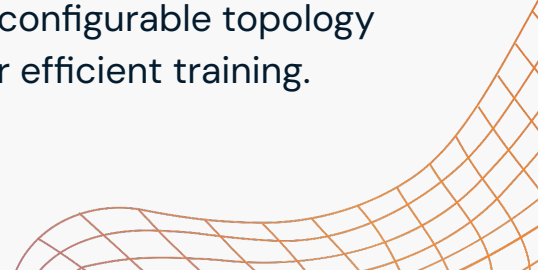
Data Center Scalability

- Supports incremental deployment and seamless expansion.
- No need to prebuild spine capacity upfront.

Rapid Tech Refresh

- Mix different hardware generations with WDM interoperability.
- Enables ongoing upgrades without downtime.

ML Training Workloads

- Handles predictable, high-bandwidth communication patterns.
 - Provides low latency and reconfigurable topology for efficient training.
- 



Traditional vs. Jupiter vs. Apollo

Feature	Traditional Clos	Jupiter	Apollo
Topology	3-tier Clos	Direct-connect + OCS	Fully optical, spine-free
Scalability	Rigid, prebuilt	Incremental via OCS	Modular, pay-as-you-grow
Tech Evolution	Disruptive upgrades	Multi-gen coexistence	Seamless multi-gen integration
Power Efficiency	Low	Medium	High
Latency	Moderate-High	Lower (1.4 hops avg.)	Very Low
Traffic Engineering	Static (ECMP)	SDN + OCS dynamic TE	SDN + OCS dynamic TE
ML Optimization	Poor fit	Supported	Ideal for ML workloads

Future Outlook

Ultra-Fast Switching ($<1\mu\text{s}$):

- Pushing OCS technology toward microsecond-scale switching
- Enables more dynamic and even per-flow reconfiguration

Beyond the Data Center:

- Extending optical switching to inter-datacenter and campus-scale networks

Smarter Control with ML:

- Research in topology prediction, traffic forecasting, and automated reconfiguration



Thanks!

Do you have any questions?

References

[1] Jupiter Evolving – SIGCOMM 2022

[2] Mission Apollo – arXiv 2023

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