DARPA Workshop on Data in the Optical Domain

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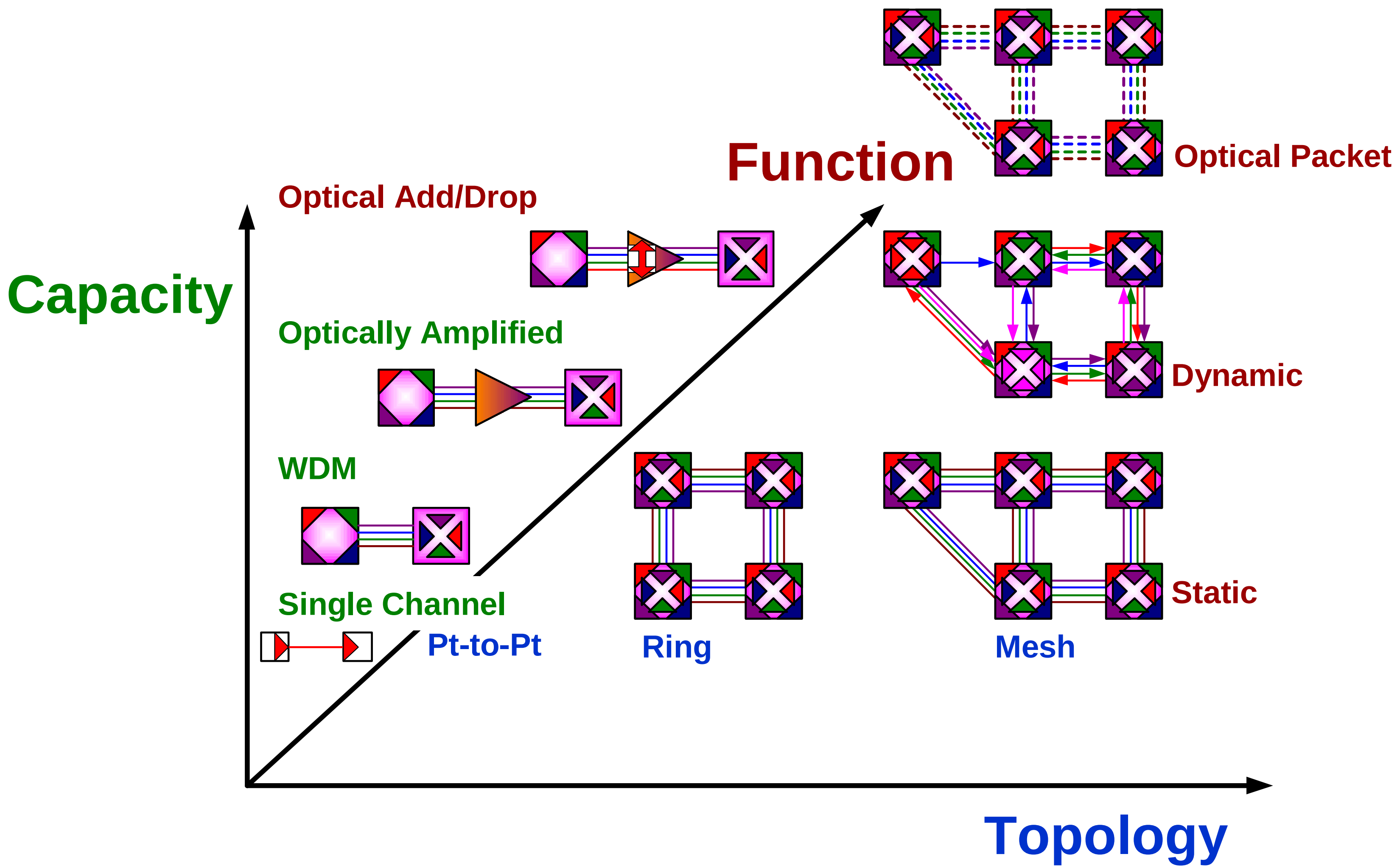
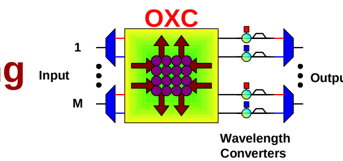
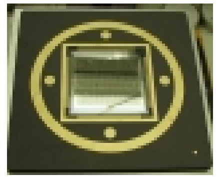
Directions in Optical Networks



Directions in Optical Technology



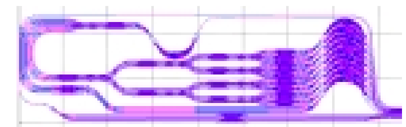
Wavelength Non-blocking Optical Crossconnect



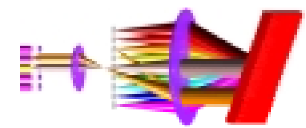
MEMS Large-scale Optical Crossconnect

Scale

Optical Add/Drop Multiplexer

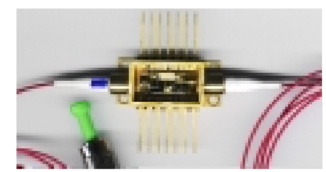


Wavelength-Selective Switch

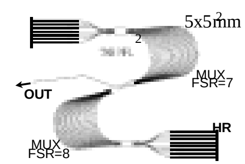


Optical Switch
(InP, $LiNbO_3$, SiO_2/Si...)

Optical Wavelength Converter



Fast-tunable Laser



Optical Fiber
Laser
Modulator
Detector

Integrated Laser/Modulator

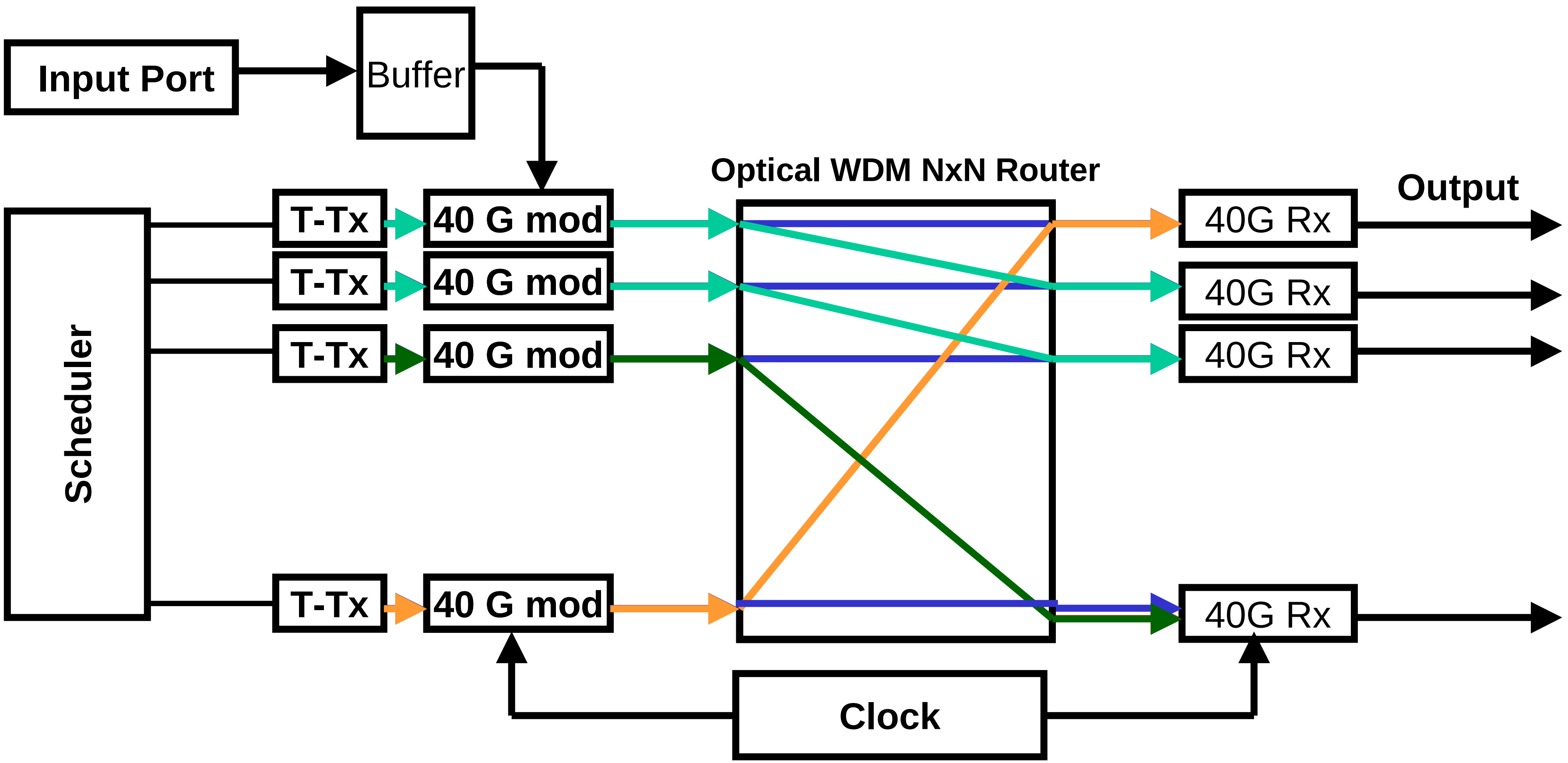
Optical Amplifier

Function

Advanced Optical Switching

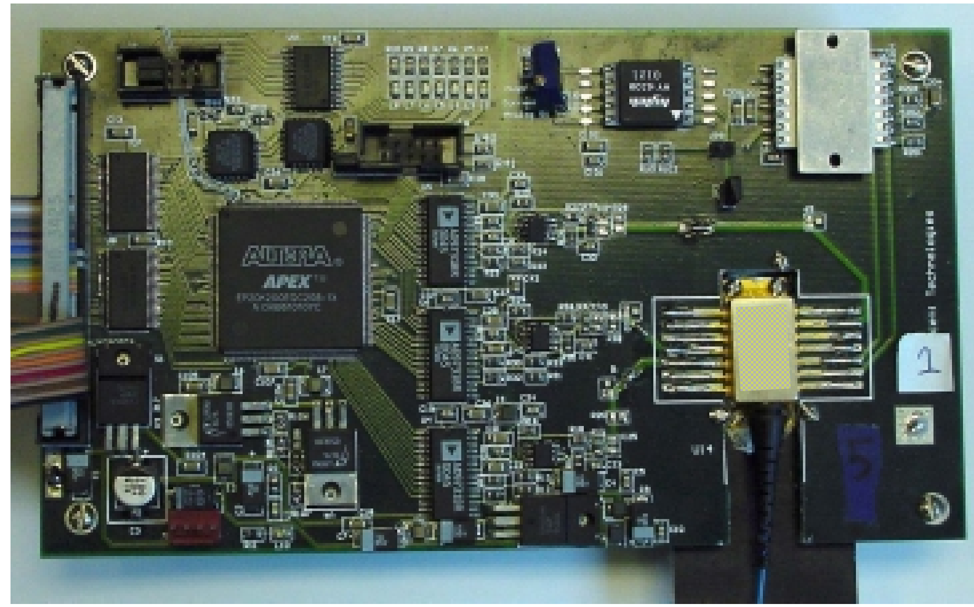
Optix Switching Fabric

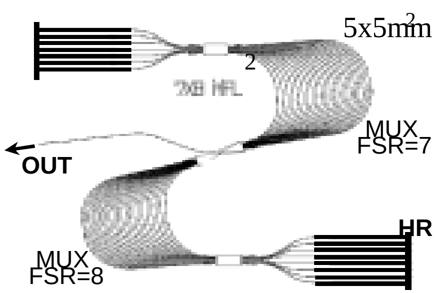
N^2 connections with N transmitters (N=32), Scalable to Multiple Tb/s



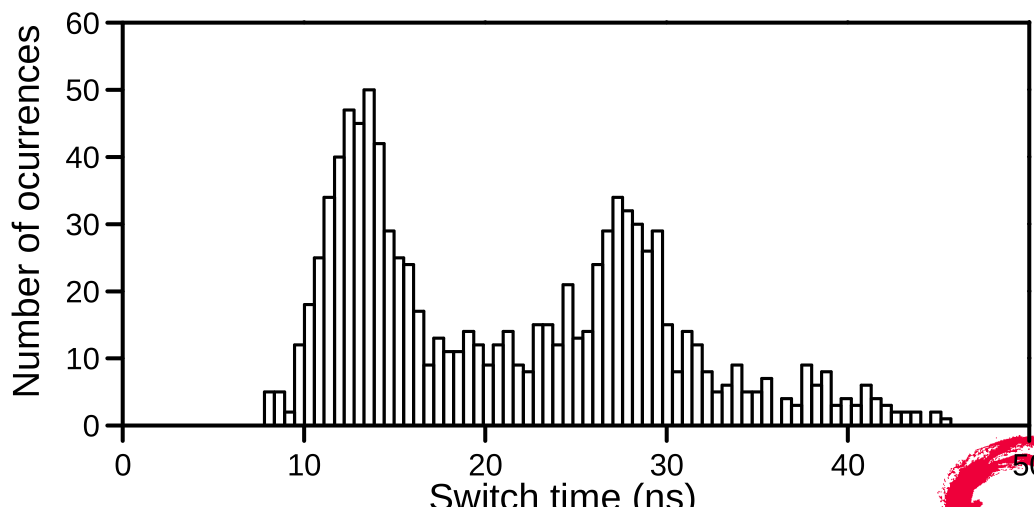
Fast-Tunable Laser Module For Advanced Networks

- Multi-section DBR laser
- 40 nm tuning range,
  0 dBm (1mW) output power
- Up to 50 channels (40 Gb/s) at
  100 GHz spacing
- Control board with FPGA and fast
  Demonstrated 32 channels
  switching switching in any
  combination D/A converter
- (992) <50 ns

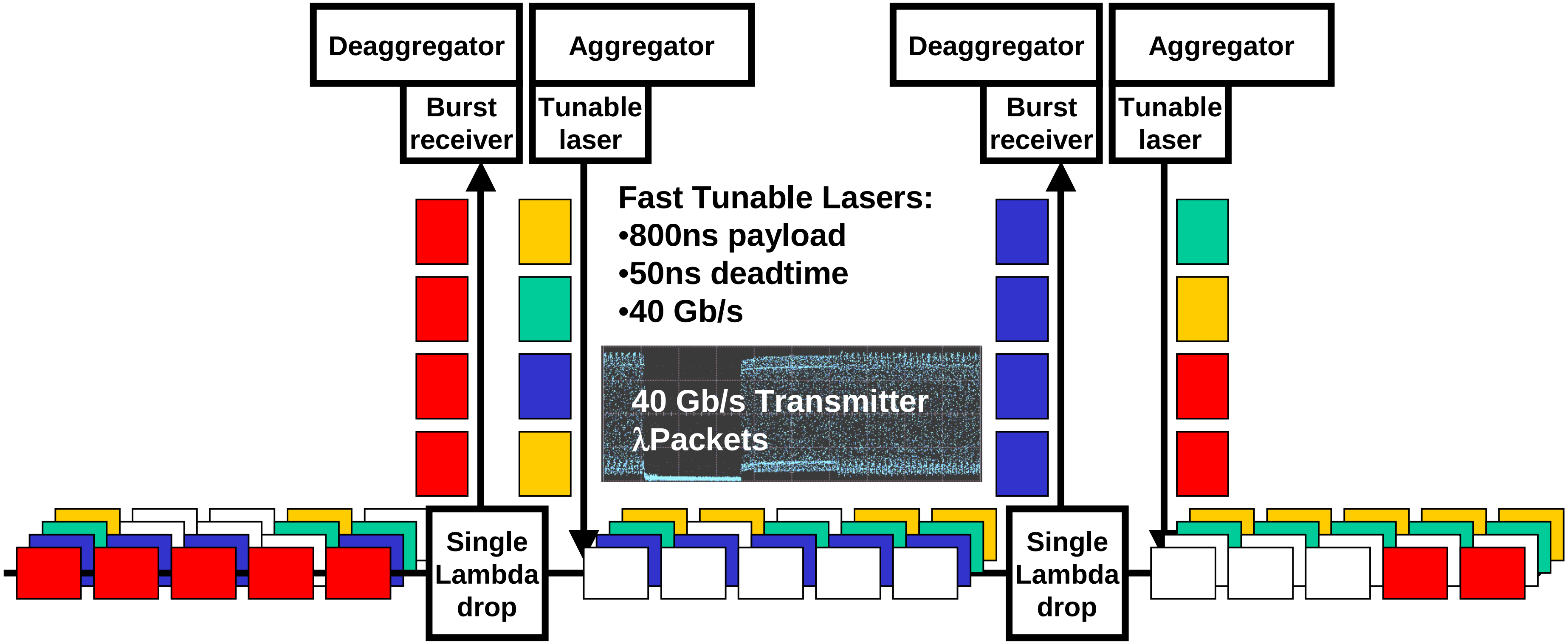




Recently demonstrated 56 channel integrated InP fast-tunable laser.

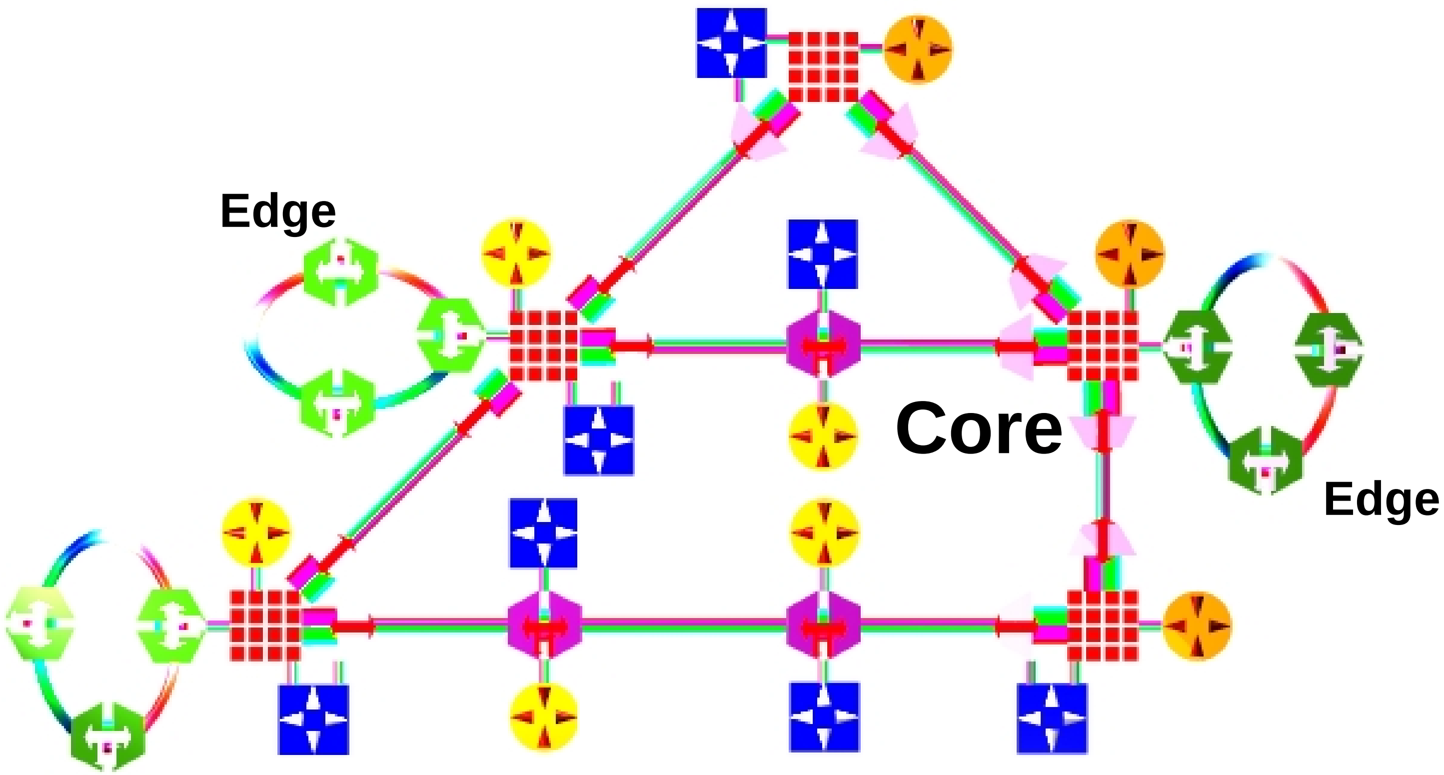


Advanced Optical Networking Concept



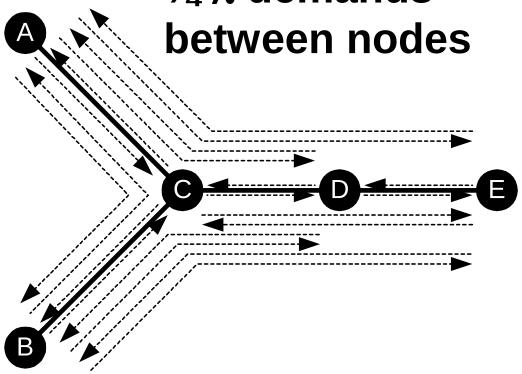
- Drop one wavelength, add multiple wavelengths
- Easy local synchronization of data insertion.
- Frame ~ 100μs-1ms.
- Guard-time 10-100ns.

Simple Transparent Core Network

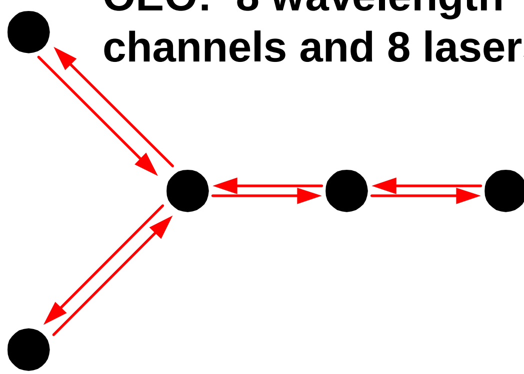


- *Simple* transparent core:
  - Optical-only domain
  - Simple network element software--provably secure?
- Edge aggregation/deaggregation--”complexity at edge”

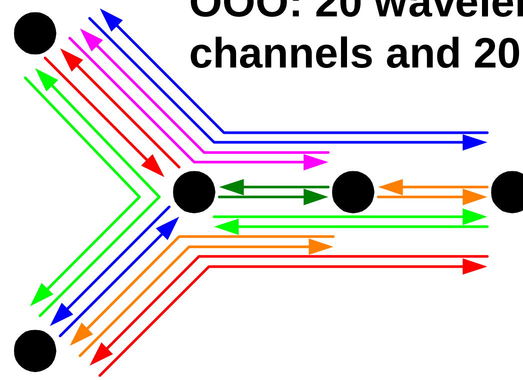
OEO, OOO & λ-Packet Comparison for a 5-Node Network



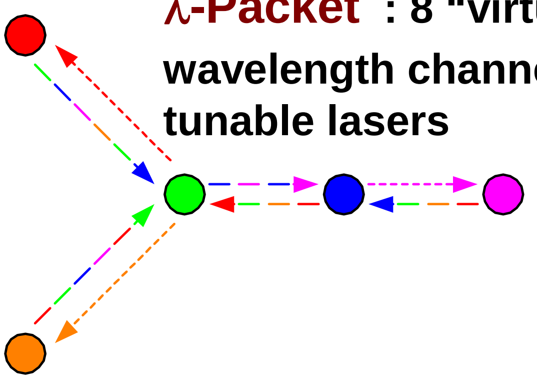
¼ λ demands between nodes



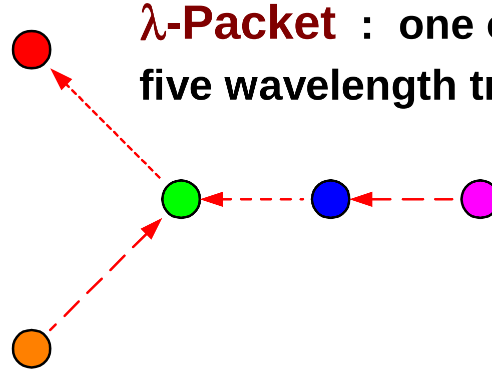
OEO: 8 wavelength channels and 8 lasers



OOO: 20 wavelength channels and 20 lasers



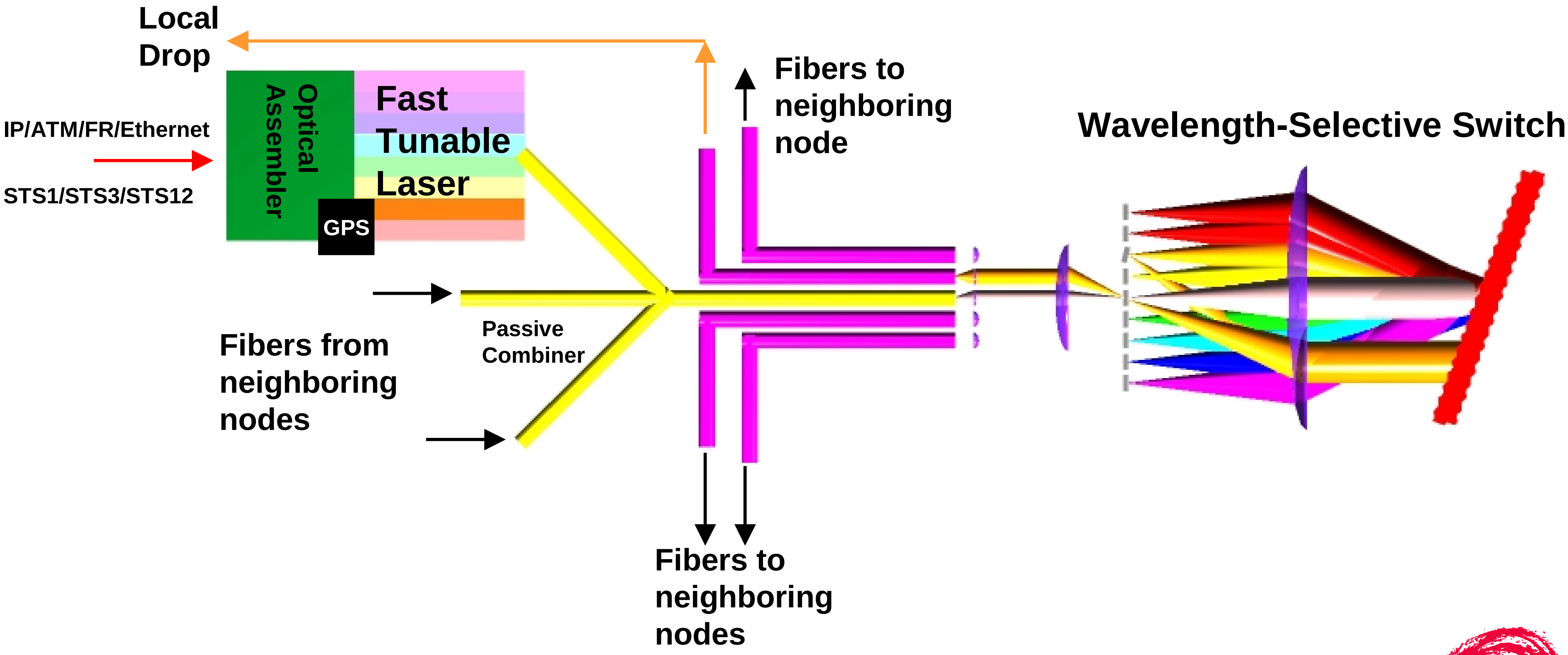
λ-Packet : 8 "virtual" wavelength channels and 5 tunable lasers



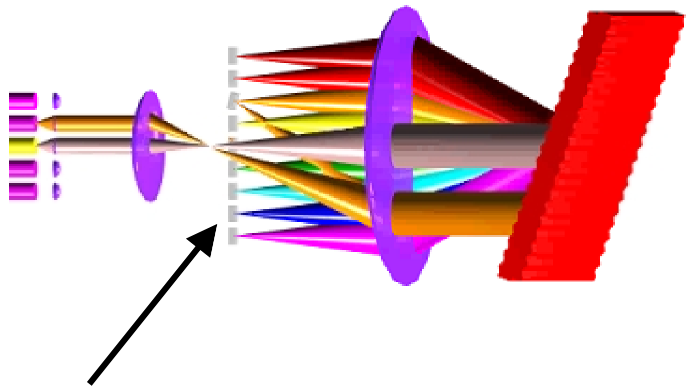
λ-Packet : one of the five wavelength trees

λ-Packet Node for Mesh Network

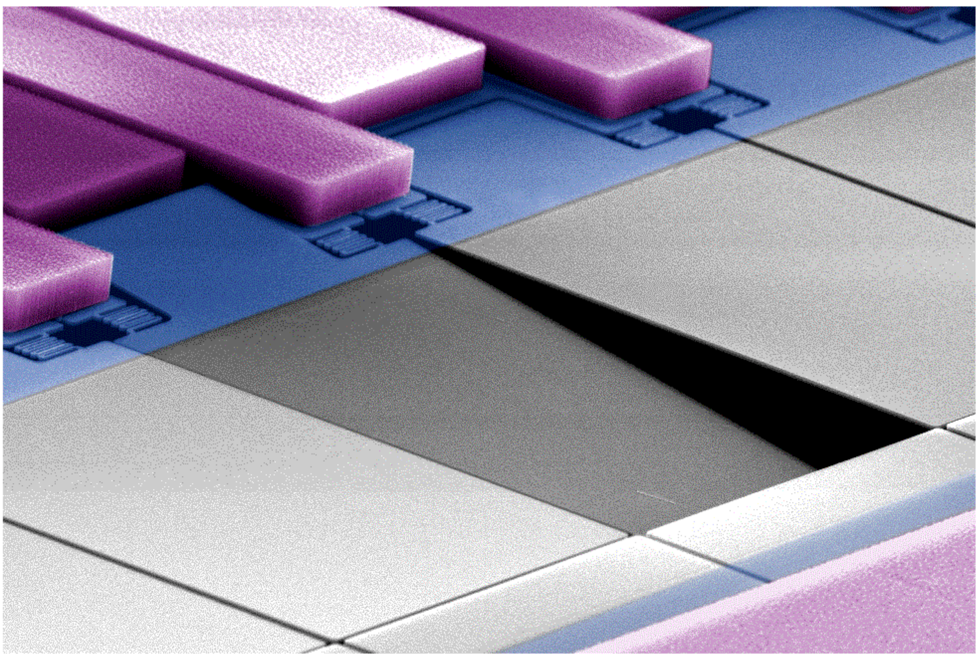
λ-Packet nodes in mesh networks require an optical assembler, tunable laser and at higher-degree nodes (d>2), a wavelength-selective switch for add/drop functionality. Accurate universal clock required for optical data interleaving (eg. ΔT of GPS clock is ~100ns).

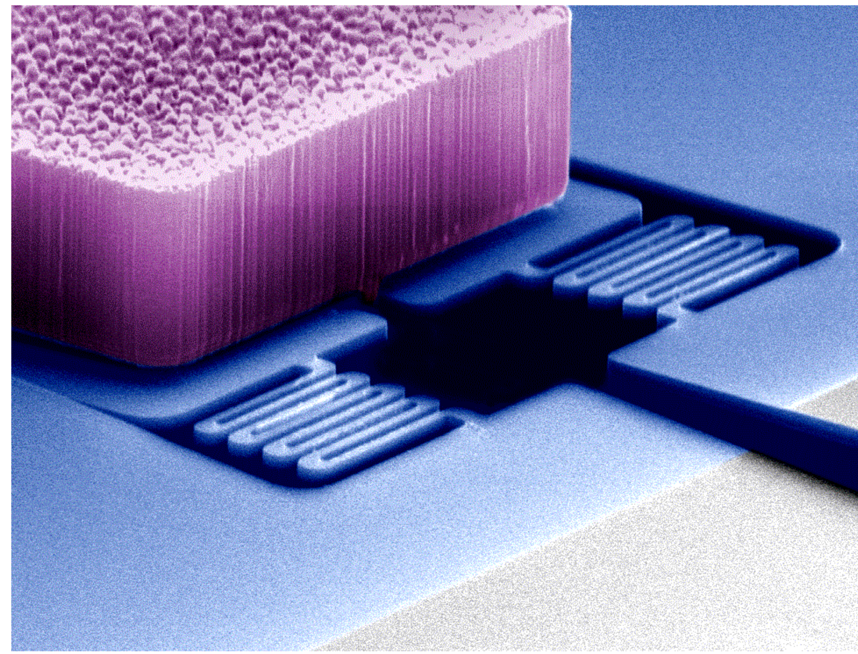


MEMS Mirror Arrays for Wavelength Selective Switches.



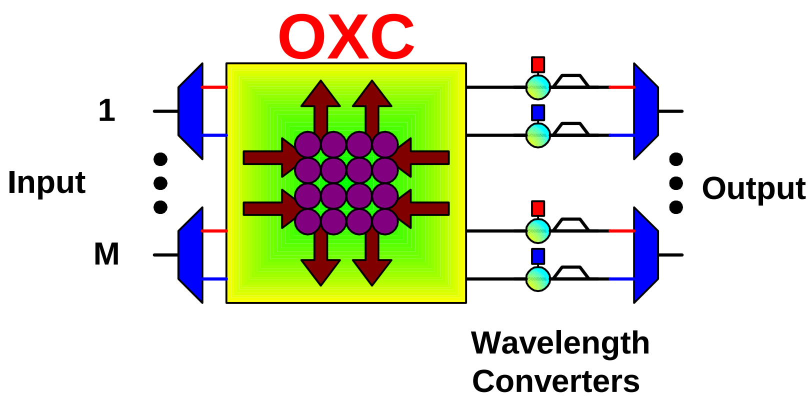
packaged switch assembly



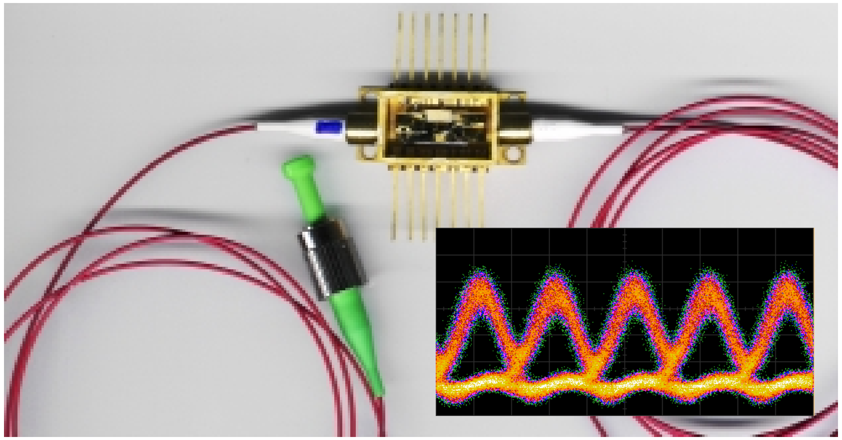


Nanofabrication capabilities enable broad design scope, uniformity, process simplification.

Wavelength-Nonblocking Optical Crossconnects
All-Optical Wavelength Conversion



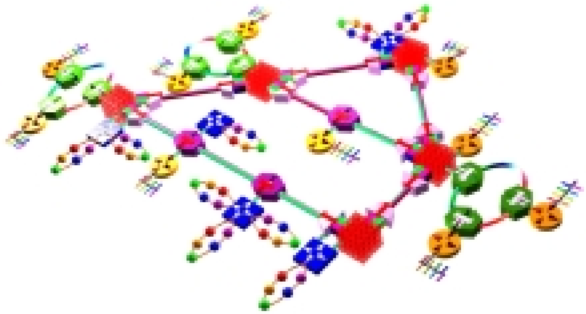
- Wavelength-nonblocking without O-E-O conversion.
- SOA/delay interferometer demonstrated to 100Gb/s
- Dedicated and shared wavelength-converter schemes. Exploit statistical/groomed traffic.



Integrated 40 Gb/s SOA/delay interferometer wavelength converter.

Advanced Optical Performance Monitoring

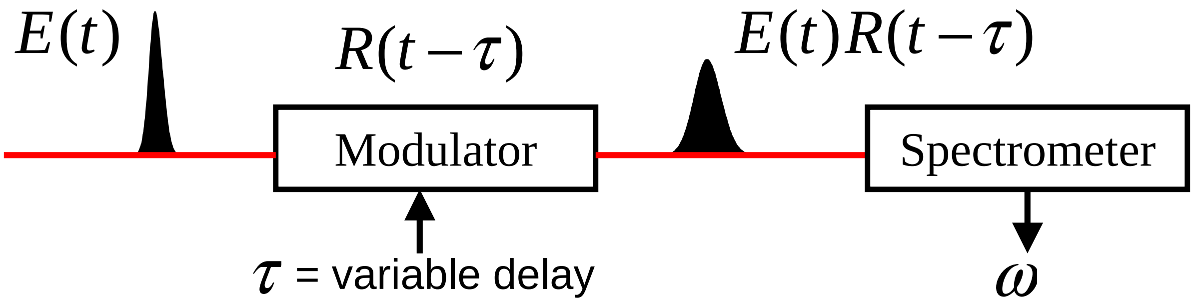
- First Generation: WDM channel presence / power and wavelength. Link status verification, gain flattening control
- Second Generation: Channel optical SNR / Q-factor. Non-alarm degradation sensing and fault localization.
- Third Generation: Feedback control to other compensators. PMD mitigation?
- Fourth Generation: Transparent (All-optical) network management. Channel performance verification after link concatenation.
- Fifth Generation: In-situ link parameter extraction from detailed channel signatures. Preplanning / preprovisioning assessment. Resource database creation.

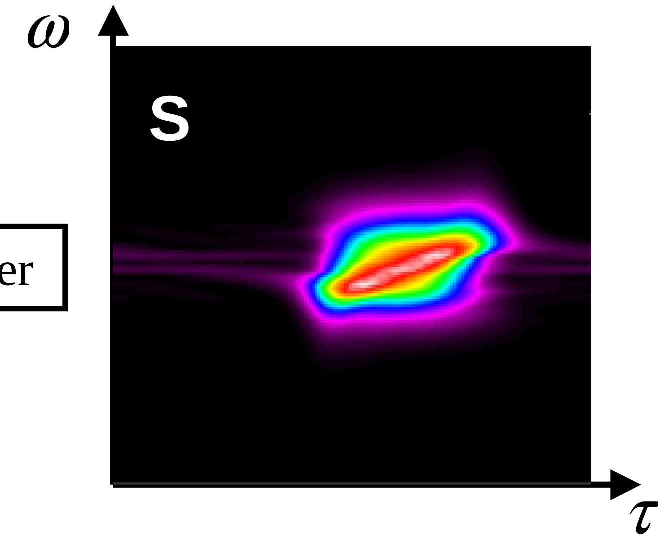


Advanced Optical Monitoring

Measurement of E (Optical Pulse) and R (Modulator) Amplitude and Phase Responses By Spectrographic Method

Spectrogram $$S(\tau,\omega) = \left| \int E(t) R(t-\tau) \exp(\omega t) dt \right|^2$$





From S, an iterative algorithm allows the simultaneous retrieval of E and R

- complete recovery of the complex quantities E and R

- no assumptions

- linear experiment, hence very sensitive