



Backbone Node High Level Requirements

**GENI Optical Workshop
September, 2007**

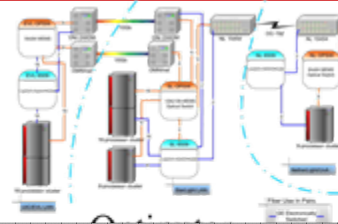
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DOCS research supported under NSF FIND Program
LASOR research supported under DARPA/MTO DoD-N Program Award Number W911NF-04-9-0001
CSWDM research supported under DARPA/MTO

Technology Push and Integration Trends

- a Transistor
- b Million to Billion transistor integration
- c Heterojunction Laser, Optical Waveguides, Integrated & Silicon Photonics
- d Heterojunction Laser, Optical Waveguides, Integrated & Silicon Photonics
- e Vertical Memory Storage

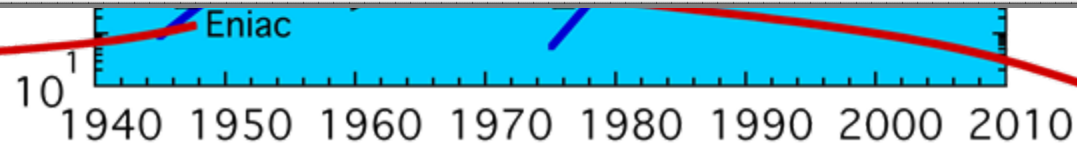
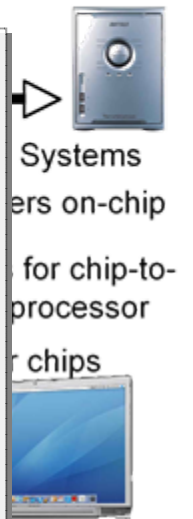
NEC earth simulator



Cisco CRS-1 (92 Tbps - 40 Racks)

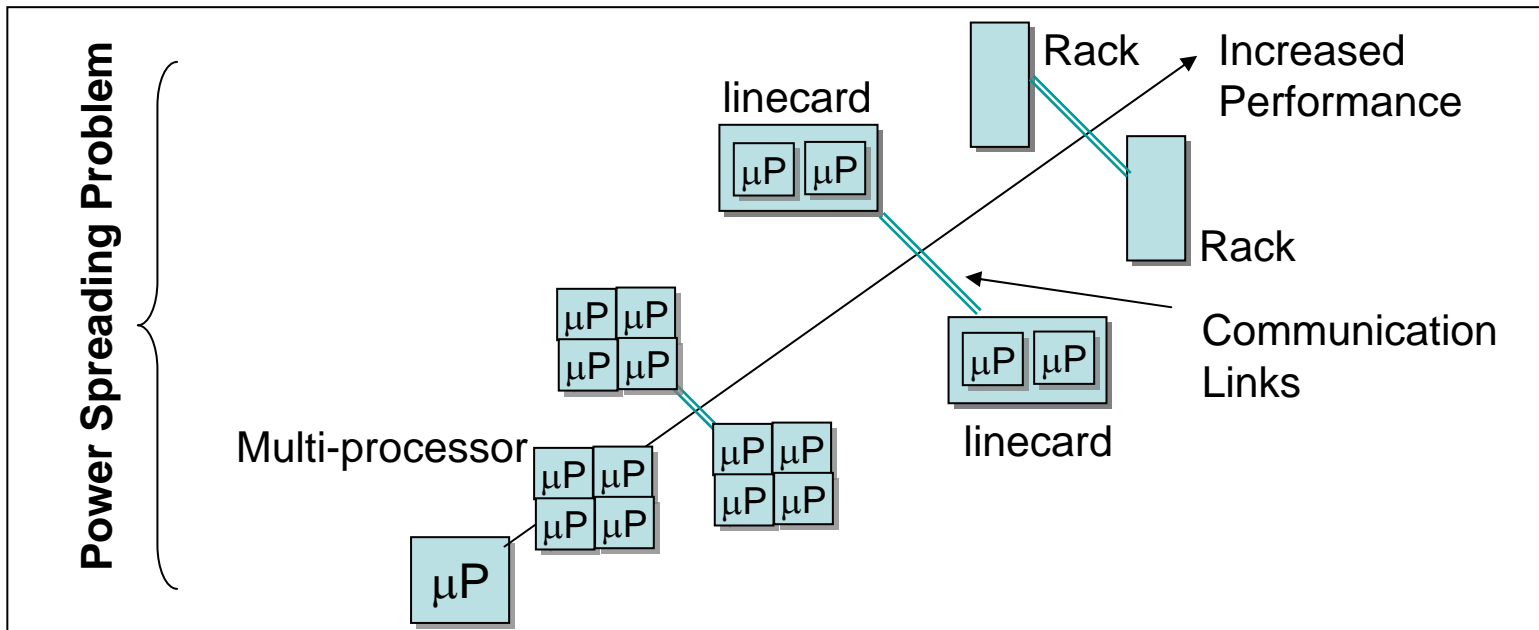
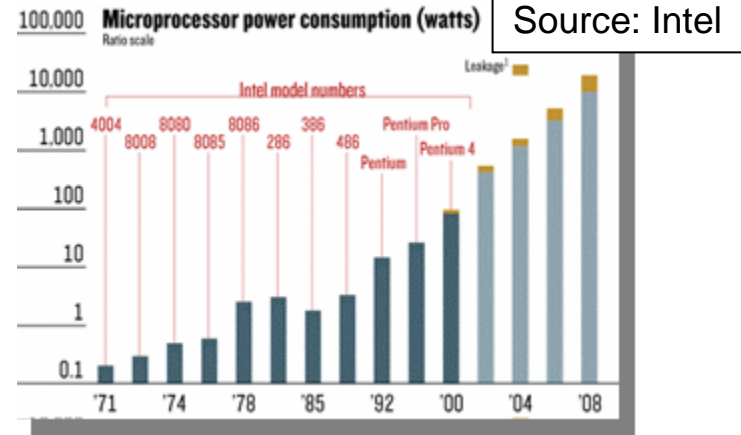


Approximately every 10 years we see the results of basic technology research reduce systems from lab size to the desktop size. This trend enables vast new applications that cannot be fully forecast.



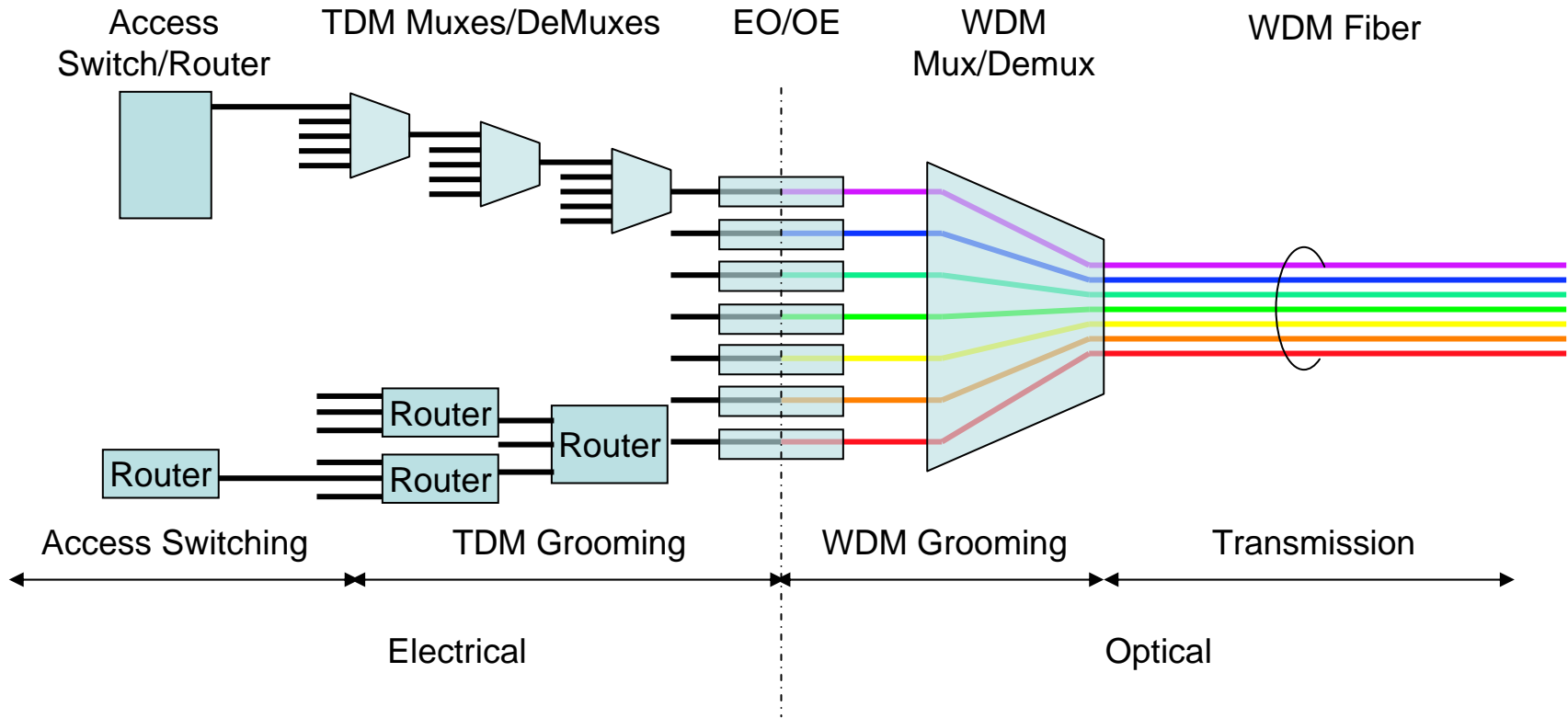
Power and Size: The Next Frontier

- *Decreased transistor size, 2x transistors on chip every 18 months, increased frequency*
- *Leakage current is huge problem, chips (hence systems) become power constrained*
- *New transistor technologies aim to decrease leakage current but requires new processing infrastructure. Costly to roll over to new foundries from current.*
- *Moving to multi-processor cores to keep up performance without increasing speed*



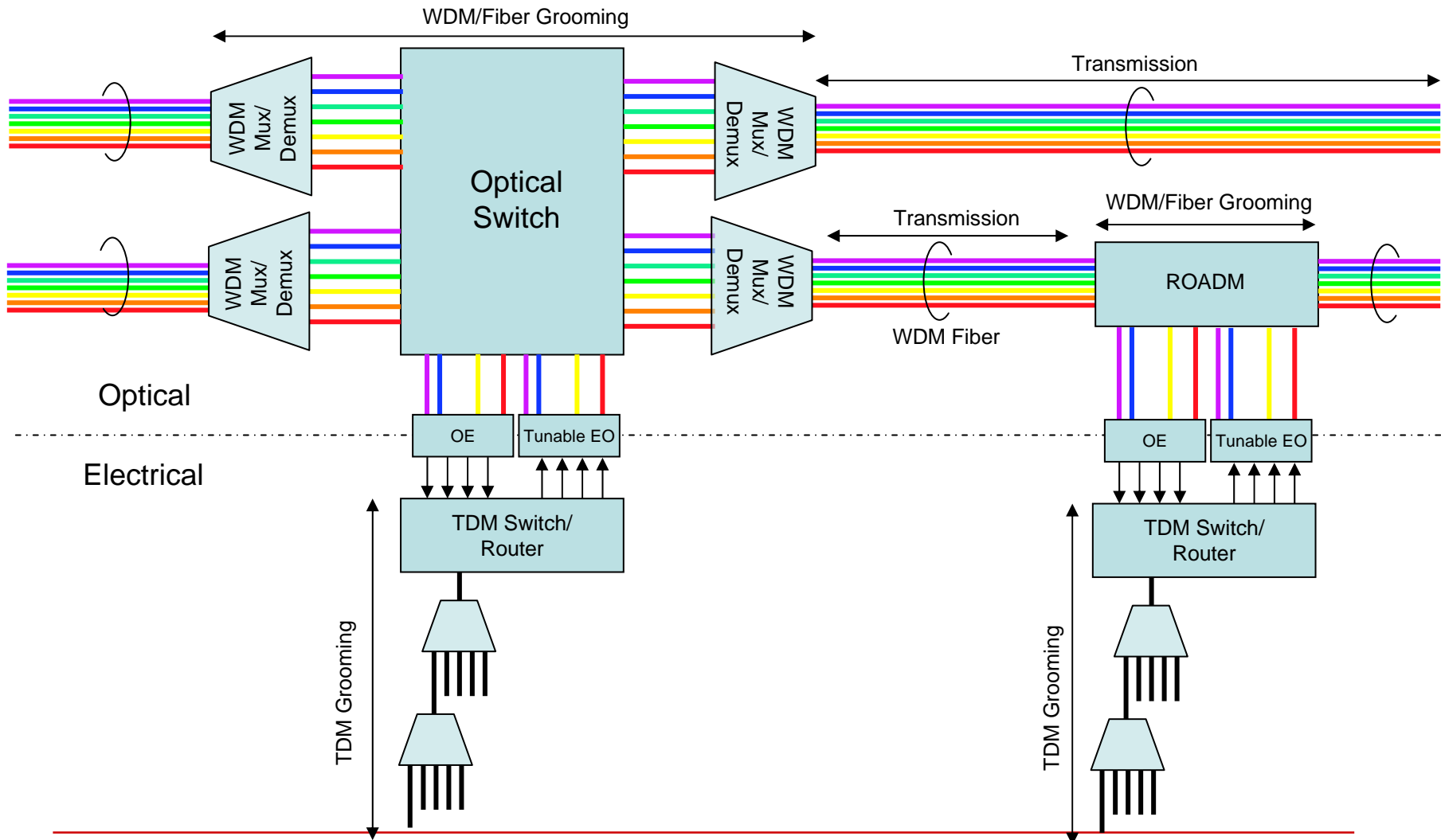
Today's Infrastructure: The Electronics/Optics Boundary

- * Current infrastructure depends heavily on electronics and optics, where the former has strength in processing and the later in transmission



Recent Progress in Optical Networking

- * Has increased the functionality and role of optics in the routing and switching at the wavelength circuit level



Bandwidth Discontinuity

Access/Enterprise/LAN

Electronic Grooming

Optical Mux/Switch/Transmission

λ λ λ λ

- There is a mismatch between the economies of transporting data in the local loop and enterprise networks and the long haul networks due to the static nature of provisioned wavelengths and the fiber plant.
- This economic mismatch will always force what is supposed to be the low cost local to pay for the interface resources and limit high data rate end to end affordable bandwidth.
 - Is there a way to better bridge the transport and local optics?
- Whatever solution, the result must be low cost integrated chips that can be used to build real systems.

Discontinuity

Once lambda is accessed, granularity is fixed till next grooming interface.

GENI BWG Optical Node and Optical Network Science Activities

D. J. Blumenthal, N. McKeown, J.
Barton and M. Masanovitch

10/9/06

Activities

- * Backbone Node High Level Requirements (HLR) GDD-06-26
 - * D. Blumenthal and N. McKeown
- * GENI Optical Networks Subcommittee
- * GENI Optical Network Science Subsection
 - * Optical Subcommittee, D. Blumenthal, J. Barton, L. Garza, M. Mashanovitch
- * Optical Section of WBS
 - * Optical system
 - * ROADMs
 - * DOS (Digital Optical Switch)
 - * Deliverables, resources, components, dependencies, cost breakdown structure, basis of cost, task schedule, baseline budget, contingency budget
 - * J. Barton, L. Garza, M. Mashanovitch, D. Casey, D. Blumenthal,

Backbone Node High Level Requirements (HLR) - GDD-06-26

- * Requirements and hi-level specifications for backbone node (exclusive of router) driven by GENI requirements.
- * Defines high level node design, operation, and specification driven by GENI research and science requirements.
- * Non-changing document.



Backbone Network Node Requirements and Architecture

Executive Summary

This document describes the high-level functional requirements of a GENI Backbone node, and a proposed node architecture. In this first draft, the basic blocks are described. The idea is that the high-level description in this document will be followed by specific documents for each building block (Packet Processing System, Programmable Framer, Fast Circuit Switch, and Wavelength Selective Switch).

- References and points to other documents for design and specification of subsystems and code.
- Will be handed over to winning contracting office to spec, RFI, RFP, and RFQ phases as well as network build.

GENI Optical Subcommittee

- * Purpose is to update community on GENI and backbone network and solicit input and feedback from optics community on
 - * Optical science on GENI
 - * BB design
 - * BB capabilities
- * Committee consists of participants of optical network future directions workshop
- * Meetings are run via Web, documents, meeting notes, etc posted
- * First output of subcommittee is to write optical network science section for Dave Clarke's larger science document. Three subsections are
 - * Applications Science
 - * Architecture Science
 - * Physical Layer Science

Optical Subcommittee

http://www.ocpn.ece.ucsb.edu/GENI/GENI_Information.html



GENI Optical Backbone Subcommittee Information

Meeting Information
 Subcommittee Name
 Group E-mail address: ocpn@ocpn.ece.ucsb.edu
 OCPN Public Website: www.ocpn.ece.ucsb.edu

Meeting Information

Date: Friday, October 5, 2007
Time: 1:30 pm - 3:00 pm
Call in Number: 1 800 255 1000
Account Code: 214470
Website Link: <http://www.ocpn.ece.ucsb.edu/geni/ocpn.html>

Agenda

Topic	Author	View
OCNP Backbone Node Hardware Architecture	Stan Muthuswamy & Sara Prucnel	View
OCNP Framework for Network Protocols	Jerry Boylston	View
Wireless and Sensor Networks	Wenduo Gong	View
4th Annual User "Hack" Party for OCPN	Geni SubCom	View
Meeting Notes from September 20, 2006	Group	View
Meeting Notes from September 7, 2006	Group	View

Subcommittee Members

Name	Role	Affiliation	E-mail Address	Subgroup
Aravind	Member	University of California, Irvine	aravind@uci.edu	
Bartlett	Member	UCSB	bartlett@ocpn.ece.ucsb.edu	Physical Layer
Barton	Member	Georgia Tech	barton@ocpn.ece.ucsb.edu	Architecture
Cheng	Member	UCSB	cheng@ocpn.ece.ucsb.edu	
Chungming	Member	UCSB	chungming@ocpn.ece.ucsb.edu	Physical Layer, Lead
Debabasis	Member	UCSB	debabasis@ocpn.ece.ucsb.edu	
John	Member	UCSB	john@ocpn.ece.ucsb.edu	Physical Layer
Prucnel	Member	UCSB	prucnel@ocpn.ece.ucsb.edu	Physical Layer
Stan	Member	UCSB	stan@ocpn.ece.ucsb.edu	Physical Layer
Wenduo	Member	UCSB	wenduo@ocpn.ece.ucsb.edu	Physical Layer
Yan	Member	UCSB	yan@ocpn.ece.ucsb.edu	Physical Layer
Yong	Member	UCSB	yong@ocpn.ece.ucsb.edu	Physical Layer
Zhao	Member	UCSB	zhao@ocpn.ece.ucsb.edu	Physical Layer

Sub-committee members (42)

Application Drivers

- * Jerry (lead)
- * Q. Chungming
- * Paul Prucnel

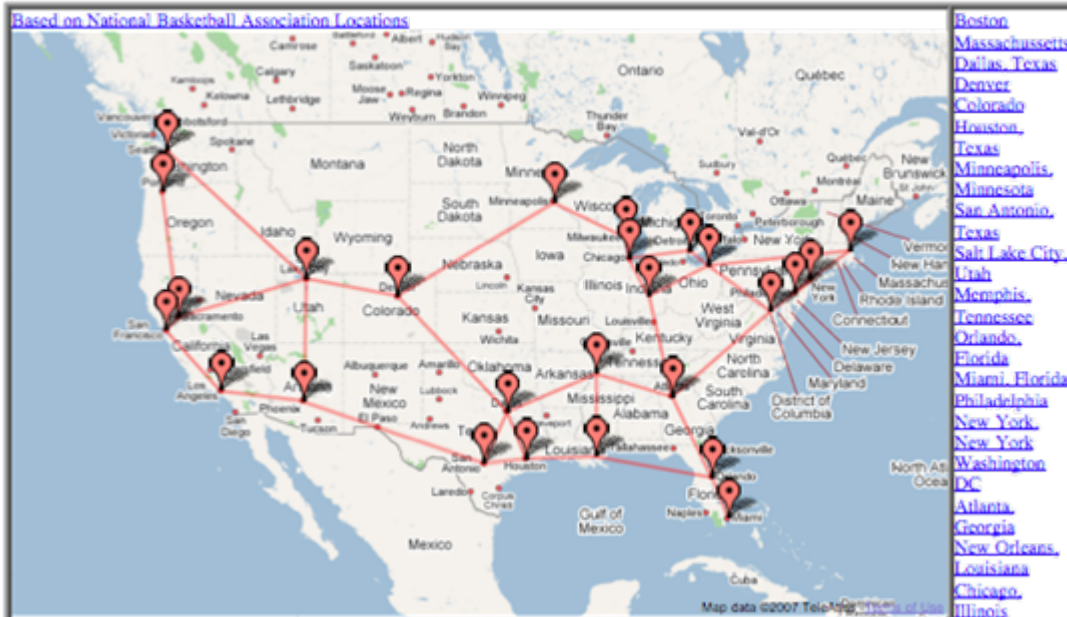
Architecture

- * Jerry (lead)
- * Q. Chungming
- * Keren Bergman
- * Debasis Mitra

Physical Layer

- * John Bowers (lead)
- * Paul Prucnel
- * Jerry
- * Debasis
- * Jon Barton
- * Milan Mashanovitch

GENI National Backbone - NBA City Map

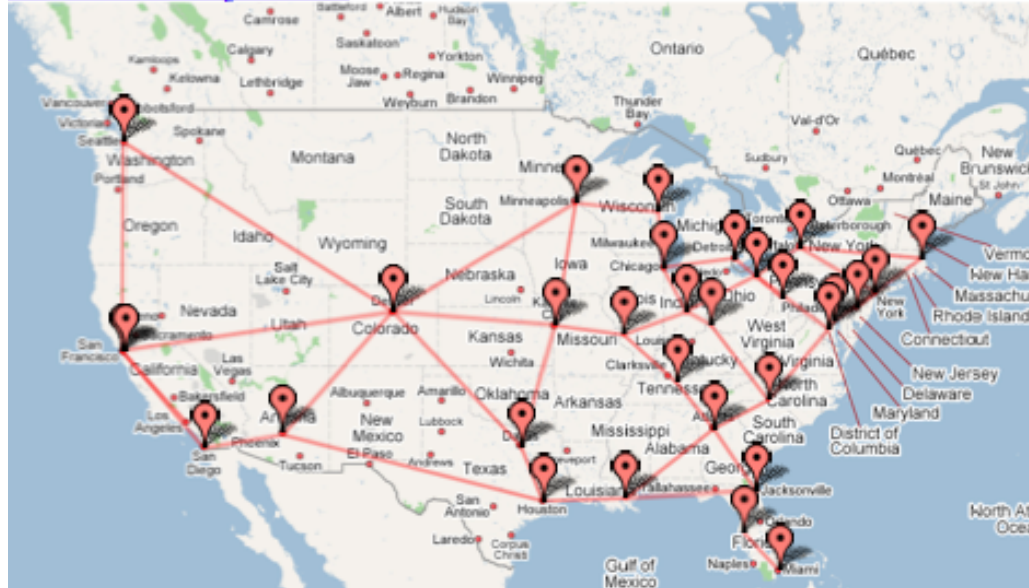


Straight line distances

- From Boston To Cleveland 885.40 km Number of repeaters: 11
- From Boston To New York 303.62 km Number of repeaters: 4
- From New York To Philadelphia 132.27 km Number of repeaters: 2
- From Washington DC To Philadelphia 330.93 km Number of repeaters: 4
- From Washington DC To Atlanta 873.27 km Number of repeaters: 11
- From Orlando To Atlanta 646.03 km Number of repeaters: 8
- From Orlando To Miami 331.11 km Number of repeaters: 4
- From Orlando To New Orleans 859.38 km Number of repeaters: 11
- From Houston To New Orleans 510.49 km Number of repeaters: 6
- From Houston To Dallas 363.09 km Number of repeaters: 5
- From Houston To San Antonio 305.40 km Number of repeaters: 4
- From San Antonio To Dallas 406.95 km Number of repeaters: 5
- From San Antonio To Phoenix 1363.99 km Number of repeaters: 17
- From Los Angeles To Phoenix 578.51 km Number of repeaters: 7
- From Phoenix To Salt Lake city 815.44 km Number of repeaters: 10
- From Los Angeles To San Francisco 557.03 km Number of repeaters: 7
- From Sacramento To San Francisco 120.31 km Number of repeaters: 2
- From Sacramento To Portland 780.28 km Number of repeaters: 10
- From Seattle To Portland 234.33 km Number of repeaters: 3
- From Seattle To Salt Lake City 1128.79 km Number of repeaters: 14
- From Sacramento To Salt Lake city 857.89 km Number of repeaters: 11
- From Denver To Salt Lake city 596.70 km Number of repeaters: 7
- From Denver To Dallas 1068.32 km Number of repeaters: 13
- From Memphis To Dallas 676.00 km Number of repeaters: 8
- From Memphis To Atlanta 542.06 km Number of repeaters: 7
- From Memphis To New Orleans 578.42 km Number of repeaters: 7
- From Indianapolis To Atlanta 688.06 km Number of repeaters: 9
- From Indianapolis To Cleveland 423.27 km Number of repeaters: 5
- From Washington DC To Cleveland 491.53 km Number of repeaters: 6
- From Detroit To Cleveland 145.28 km Number of repeaters: 2
- From Detroit To Chicago 381.33 km Number of repeaters: 5
- From Indianapolis To Chicago 265.17 km Number of repeaters: 3
- From Milwaukee To Chicago 131.31 km Number of repeaters: 2
- From Milwaukee To Minneapolis 479.90 km Number of repeaters: 6

GENI National Backbone - NFL City Map

Map of National Football League Locations

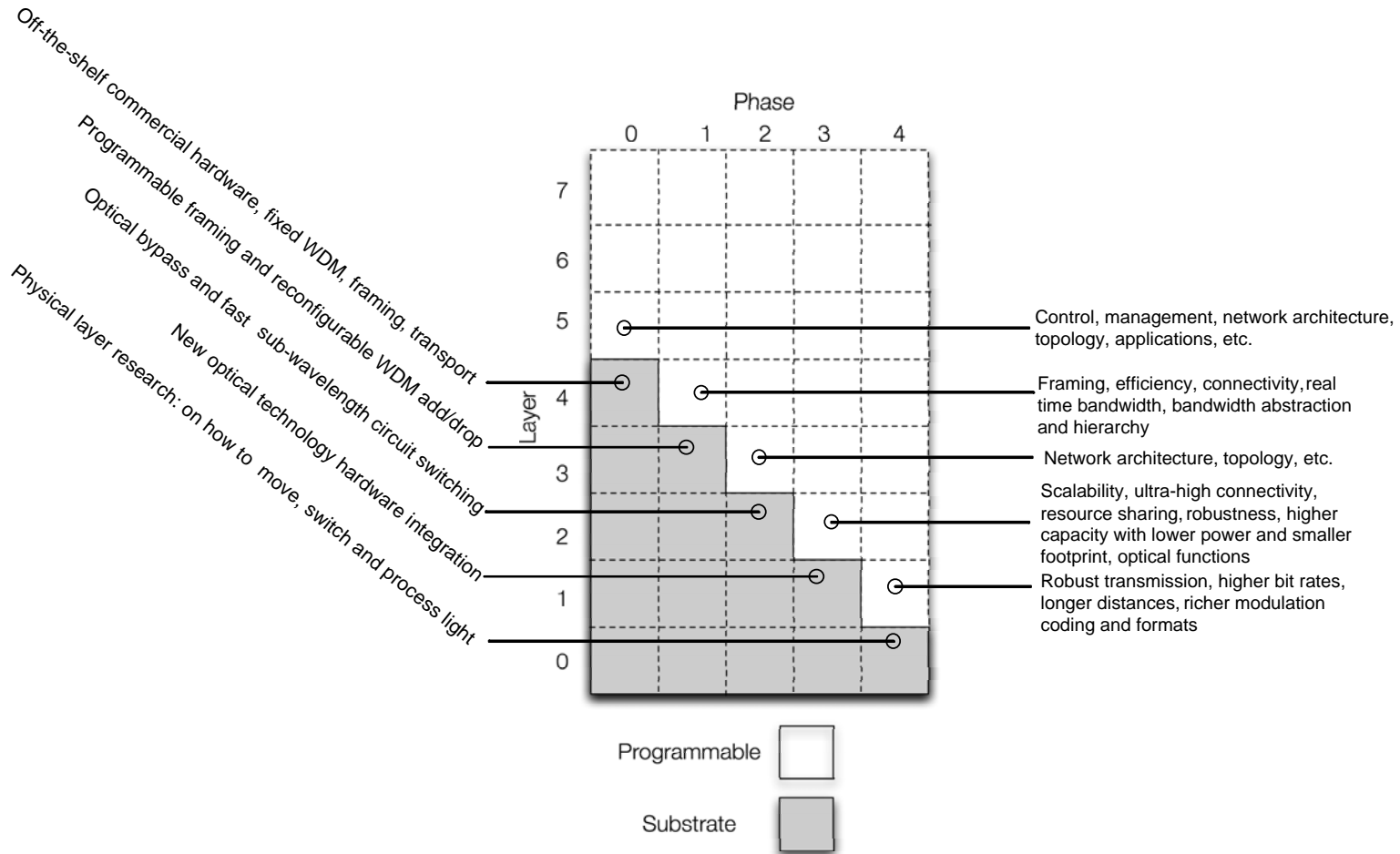


- [Boston](#)
- [Massachusetts](#)
- [Dallas, Texas](#)
- [Denver](#)
- [Colorado](#)
- [Houston, Texas](#)
- [Miami, Florida](#)
- [Philadelphia](#)
- [New York](#)
- [Minnesota](#)
- [Minnesota](#)
- [Washington](#)
- [DC](#)
- [Atlanta, Georgia](#)
- [New Orleans, Louisiana](#)
- [Chicago, Illinois](#)
- [Cleveland, Ohio](#)
- [Detroit, Michigan](#)

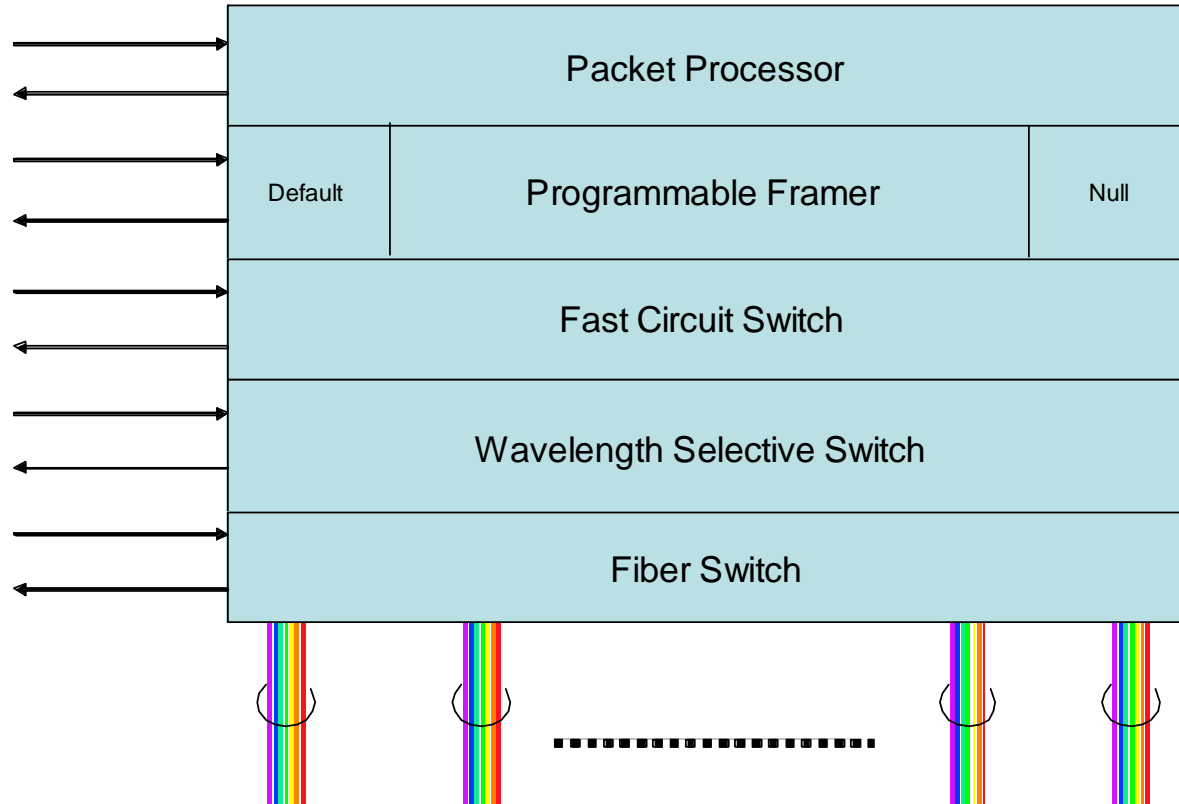
Straight line distances

- From Washington DC To Baltimore 56.73 km Number of repeaters: 1
- From Charlotte To Cincinnati 542.03 km Number of repeaters: 7
- From Indianapolis To Cincinnati 158.12 km Number of repeaters: 2
- From Kansas City To St Louis 383.99 km Number of repeaters: 5
- From Kansas City To Denver 896.75 km Number of repeaters: 11
- From Indianapolis To St Louis 371.49 km Number of repeaters: 5
- From Nashville To St Louis 408.80 km Number of repeaters: 5
- From Boston To Buffalo 642.02 km Number of repeaters: 8
- From Buffalo To Philadelphia 470.44 km Number of repeaters: 6
- From Pittsburgh To Cleveland 183.08 km Number of repeaters: 2
- From Boston To New York 303.62 km Number of repeaters: 4
- From New York To Philadelphia 132.27 km Number of repeaters: 2
- From Baltimore To Philadelphia 275.78 km Number of repeaters: 3
- From Jacksonville To Atlanta 459.70 km Number of repeaters: 6
- From Tampa To Miami 331.90 km Number of repeaters: 4
- From Jacksonville To New Orleans 811.63 km Number of repeaters: 10
- From Houston To New Orleans 510.49 km Number of repeaters: 6
- From Houston To Dallas 363.09 km Number of repeaters: 5
- From Houston To Phoenix 1634.72 km Number of repeaters: 20
- From San Diego To Phoenix 480.92 km Number of repeaters: 6
- From Phoenix To Denver 944.78 km Number of repeaters: 12
- From Los Angeles To San Francisco 557.03 km Number of repeaters: 7
- From San Diego To San Francisco 738.90 km Number of repeaters: 9
- From Seattle To San Francisco 1095.81 km Number of repeaters: 14
- From Seattle To Denver 1643.39 km Number of repeaters: 21
- From Denver To San Francisco 1526.41 km Number of repeaters: 19
- From Denver To Dallas 1068.32 km Number of repeaters: 13
- From Kansas City To Dallas 728.66 km Number of repeaters: 9
- From Nashville To Atlanta 344.88 km Number of repeaters: 4
- From Atlanta To New Orleans 684.63 km Number of repeaters: 9
- From Charlotte To Atlanta 364.82 km Number of repeaters: 5
- From Indianapolis To Cleveland 423.27 km Number of repeaters: 5
- From Washington DC To Cleveland 491.53 km Number of repeaters: 6
- From Charlotte To Washington DC 530.12 km Number of repeaters: 7

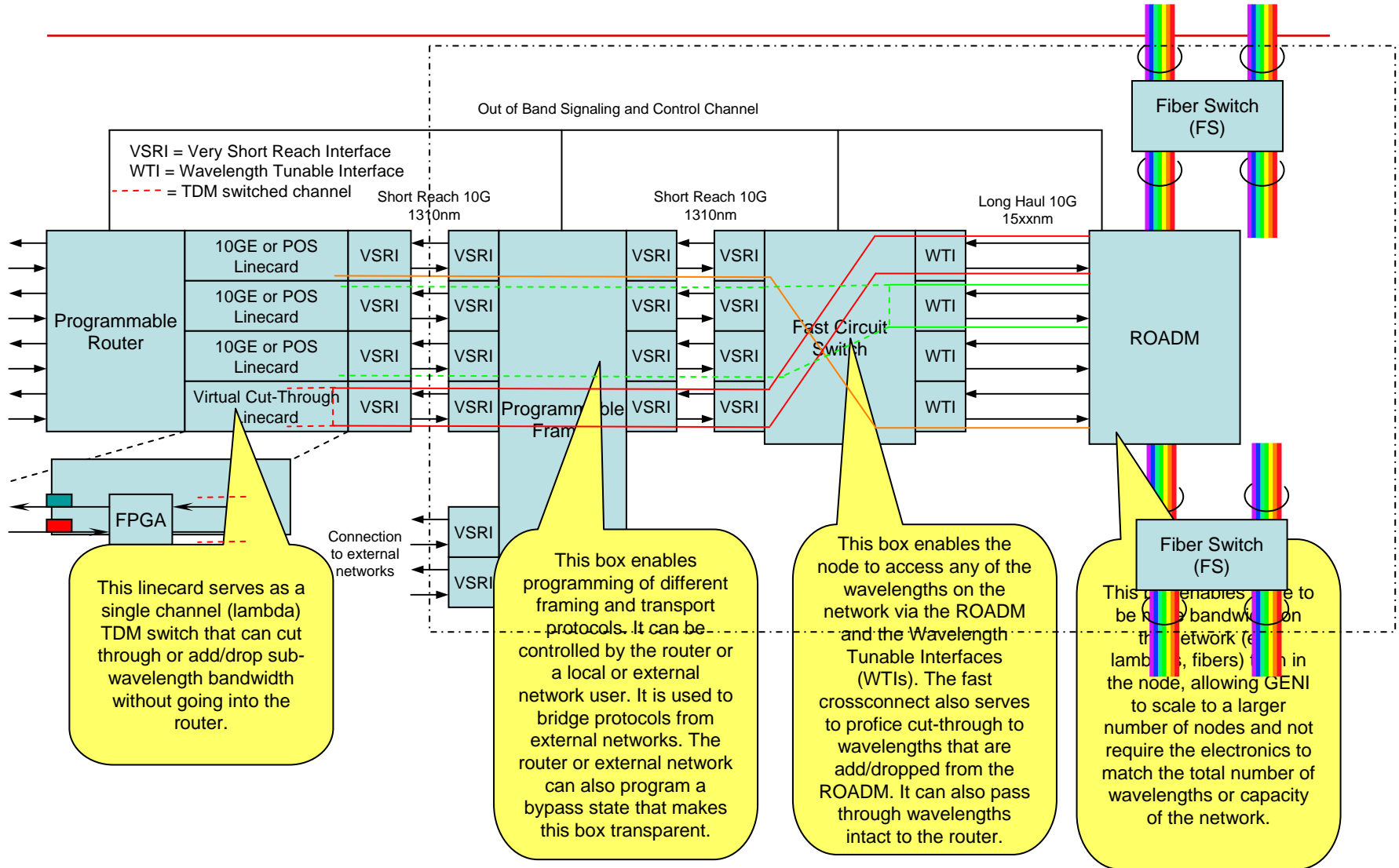
GENI Concurrent Substrate Model



Layered Research Representation



GENI Backbone Node Architecture - GDD



Application Drivers

- Consumer oriented applications such as Video-on-Demand and IPTV,
- Grid computing for:
- E-Science projects
- Business/enterprises (e.g., in healthcare, financial and defense sectors). They should be able to interconnect multiple edge devices with different data formats and support universal services (e.g., connection-oriented or connectionless) requiring different bandwidth granularities and Quality of Services (QoS) levels.
- Edge devices with end hosts (e.g., supercomputers, data servers), IP routers, Layer 2 switches (e.g. Ethernet switches), and SONET/SDH Add-Drop Multiplexers as well as base stations for wireless access (either based on RF or free-space optics).

Physical Layer

Experiments based at 3 nodes with:

- * Inexpensive switches (out of 26)
- * Separate fibers over GENI
- * Does not have any interference or interaction with other experiments
- * Minimal cost but large ROI as it speeds up the development of next generation technology over the GENI footprint.

Examples of community Physical Layer testing

- * Photonic integrated circuits (PICs) (in primarily InP and Silicon technologies).
- * Tunable laser transmitters to enable the dynamic aspects of the network
- * New multi-level coding and bandwidth efficient transmission formats
- * Agile optical frequency hopping and coherent communications
- * All optical 3R (reshaping, re-amplification, retiming) regeneration
- * All optical Wavelength conversion
- * Optical buffering and synchronizers – slow light, Silica delay lines, wavelength dependent buffering.

Physical Layer

- * Novel all-optical switching technologies
 - * MEMs
 - * ROADMs and reconfigurable OADMS to allocate wavelengths that are framing and bandwidth agnostic. Enable higher degree ROADMs with silica PLCs
- * Devices that support coherent systems such as wavelength converters that maintain phase information (4 wave mixing)
- * Re-configurability at the chip level – (similar to FPGA) Field Programmable PIC to transform static components such as lasers, and signaling in a dynamic way so that it may be controlled by electronics.
- * Technologies to reduce power dissipation – removal of Thermal-electric Cooler (TE) with better heat sinking and material choices.
- * Bandwidth improvements will be explored using new
 - * Multilevel coding techniques (DPSK, QPSK etc.) – coherent systems
 - * Traveling Wave modulators, and increasingly dense Wavelength Division Multiplexing (WDM).
- * Security can be enhanced using Quantum key and Quantum networks

Architecture

- * Mesh networks to enable a dynamic reconfigurable, high bandwidth network using state-of-the-art control plane technologies.
- * Automatic provisioning will allow self-healing at the network level. ROADMs promise to enable mesh networking that combines electronic grooming with transparent wavelength management.
- * Sensor nets – to communicate between and facilitate the routing of data collection.
- * Interaction with wireless connections – transparency of protocols and modulation format.
- * Packet switching architecture using optical headers and fast switching.
- * Moving optics inside the computer
- * Satellite communications and broadcasting of phone/TV, Internet
- * There is an opportunity to embed intelligence through integration of electronics.

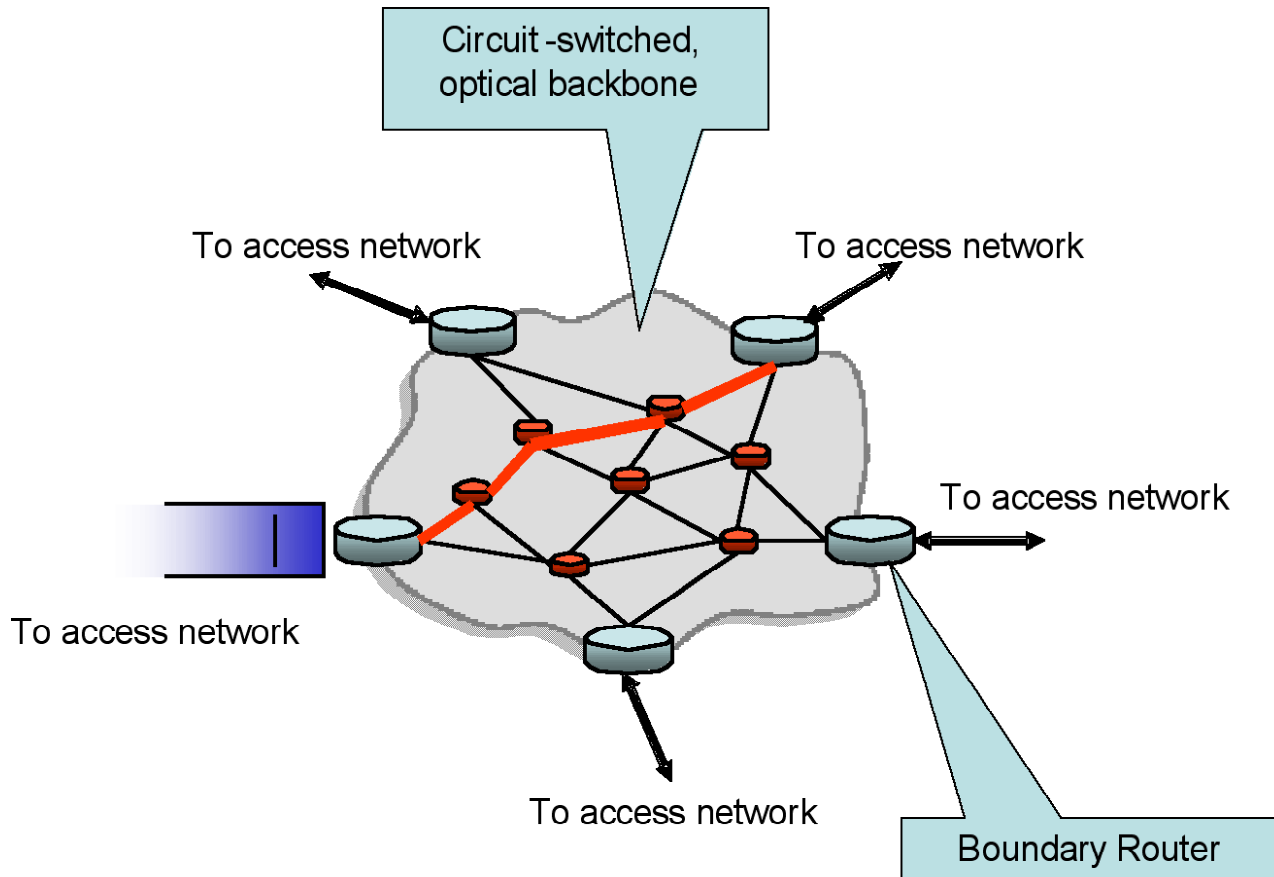
Open Issues

- * For GENI expt at what time scale would we want resources to be provisioned in the optical switch? Seconds/Tens of seconds?
- * 2. What APIs are exposed at each layer of the switch (per GDD-06-26, Fig 4)? Do we assume commercial product or something custom made?
- * 3. How is programmable framer implemented? At what granularity? How flexible is the time-slot interchange? It is going to be restricted to couple of currently used standard time slots?
- * 4. How is the optical control plane realized? In-band or out-of-band?
- * 5. What features are we expecting from a commercial switch? What APIs are we expecting from the commercial vendor for the management interface?"
- * 6. Do we request the vendor to open up the control interface of the switch? Can the vendor expose API's for injecting error frames in the data path? Can we prevent the switch from performing automatic restoration?
- * 7. Would we be able to bypass the control processor of the optical switch and control the switch from a processor running a GENI expt?
- * 8. For phase 0, do we use commercial switch and use its mgmt interface to control the switch?

FIND: Dynamic Optical Circuit Switching (DOCS)

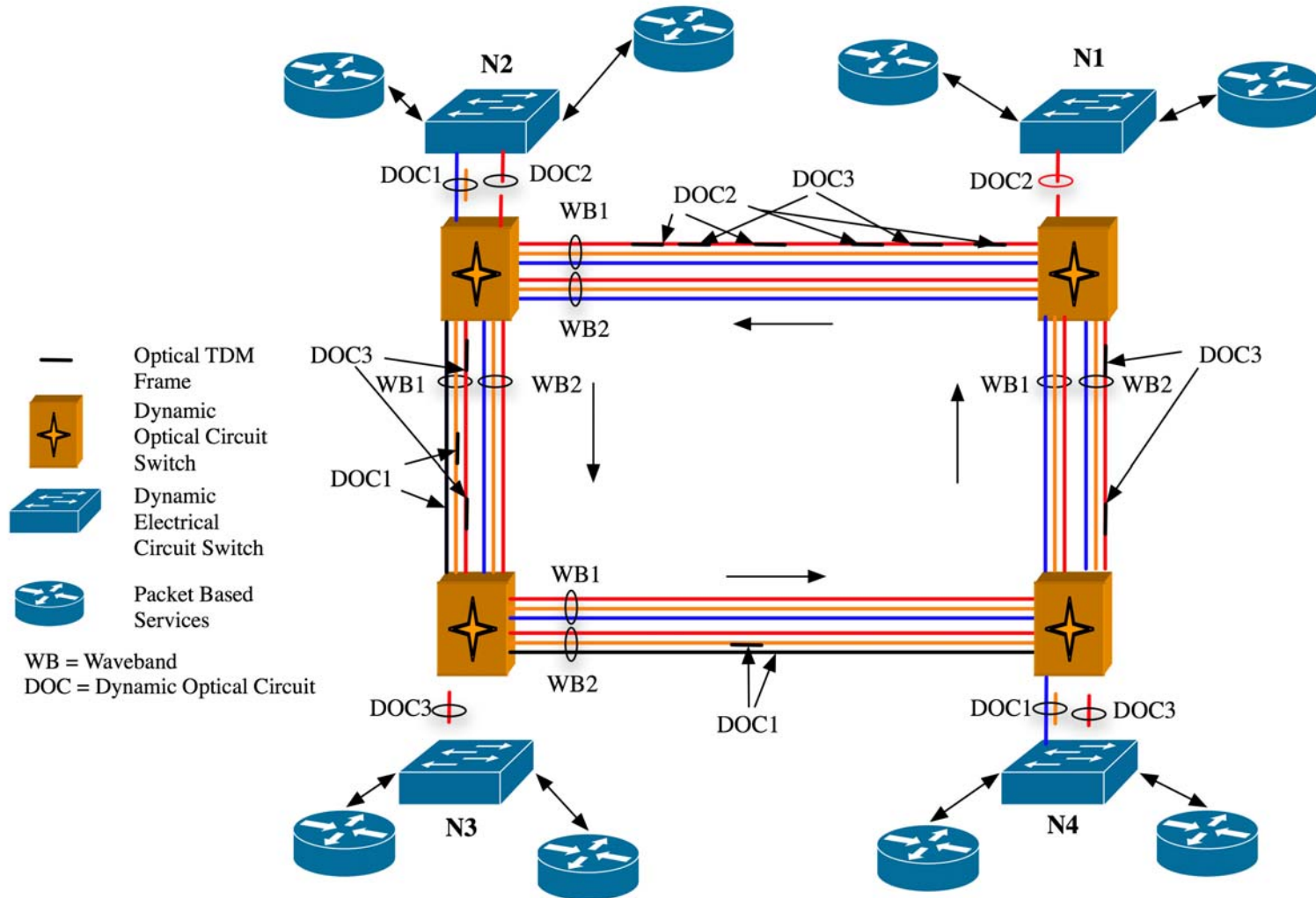
QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

- DOCS: N. McKeown, J. Bowers and B. Mukherjee



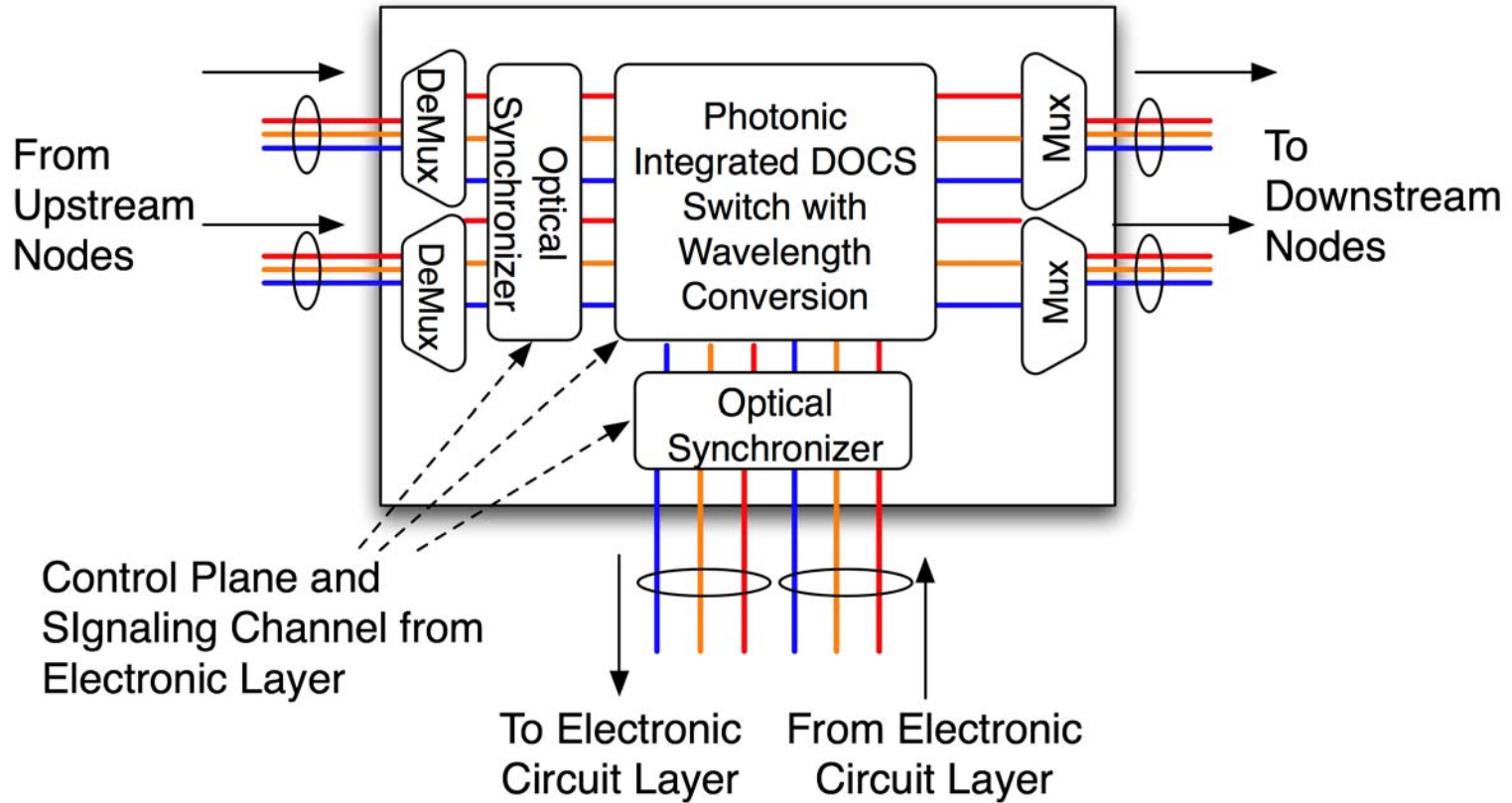
DOCS Network Example

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.



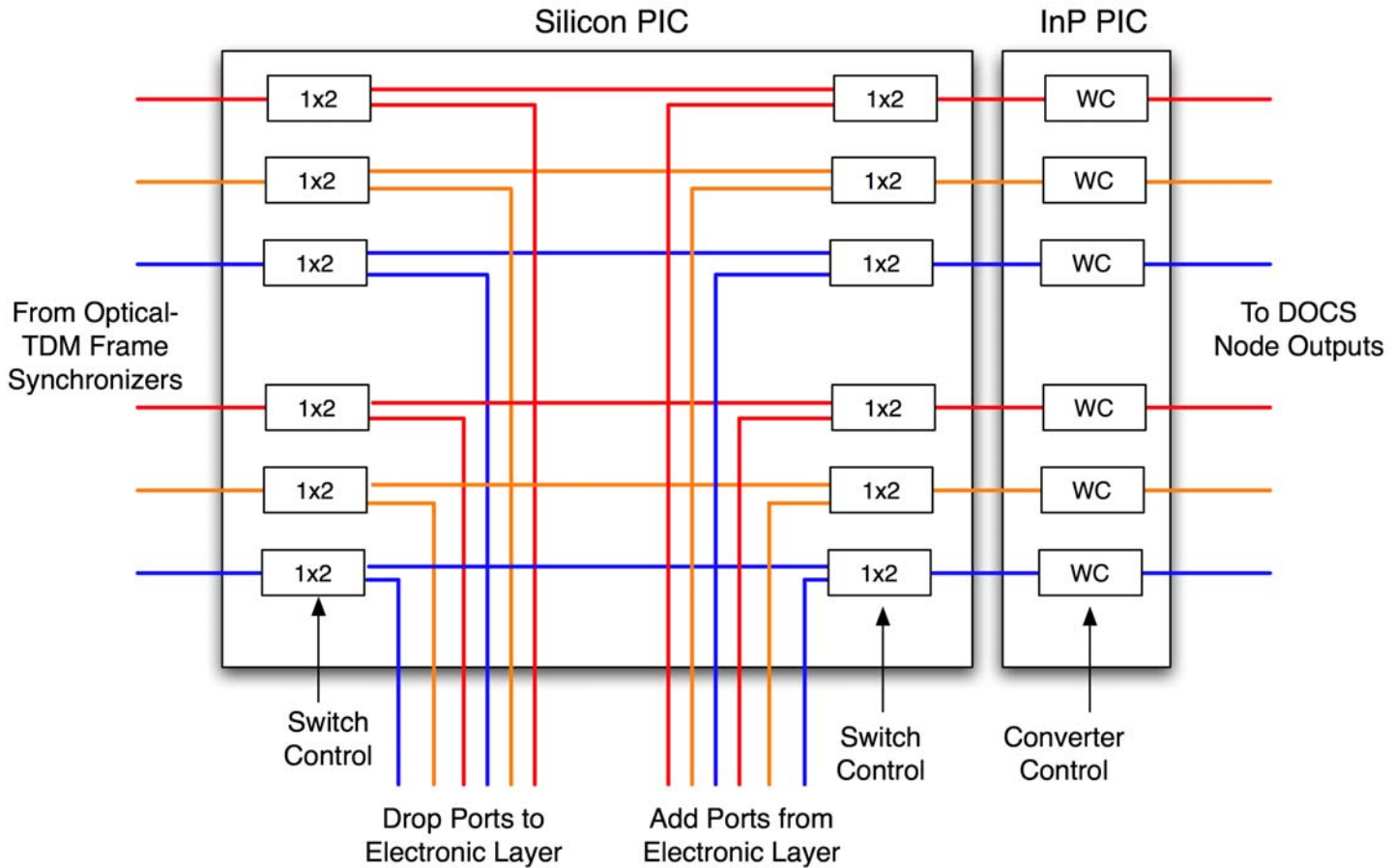
DOCS Node

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.



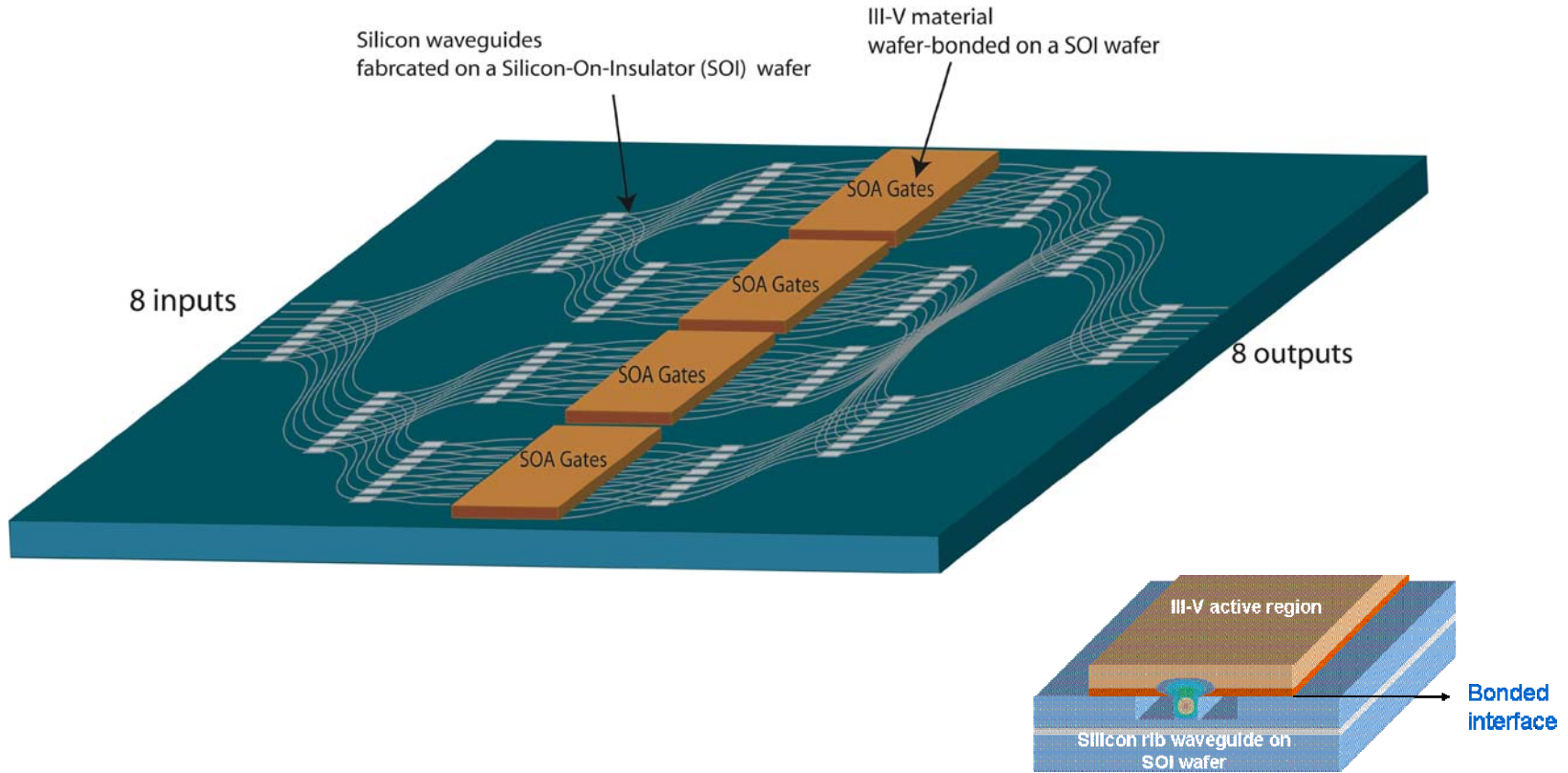
DOCs Switch

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.



Hybrid Silicon/InP Optics Implementation

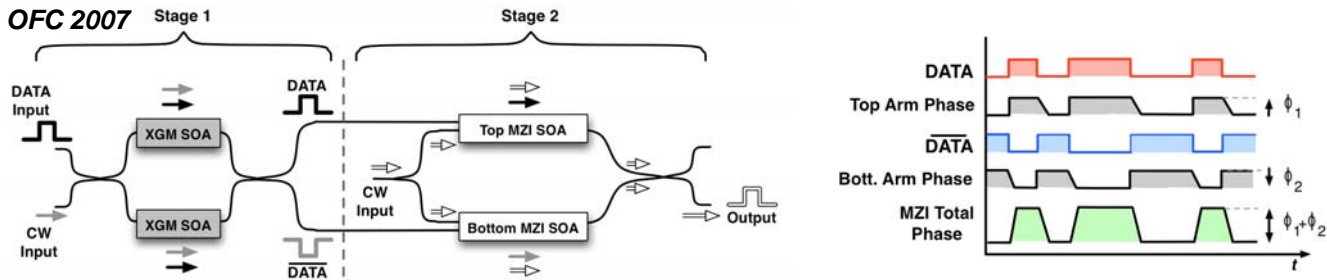
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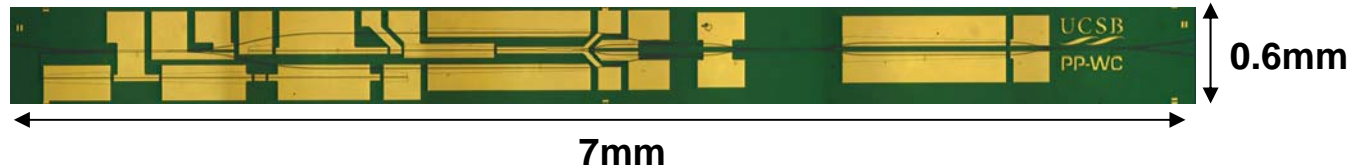
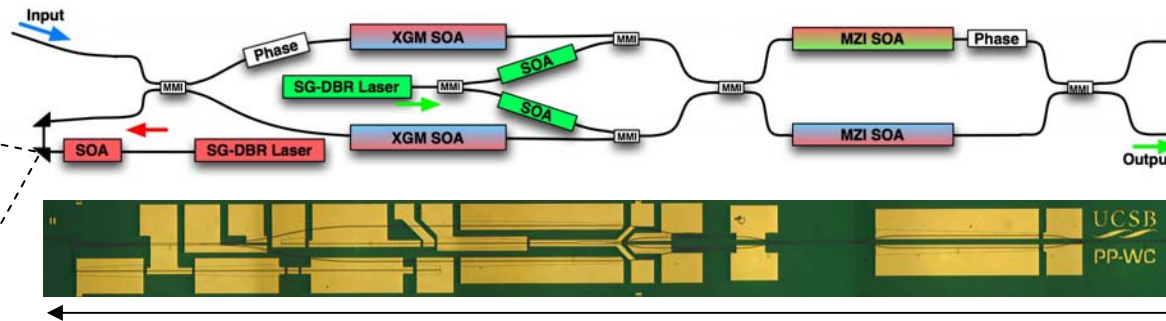
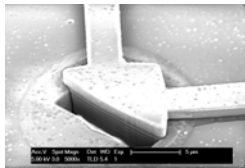
Hybrid Si Laser: Bowers et. Al.

Integrated InP All-Optical 2-Stage Push-Pull Wavelength Converters

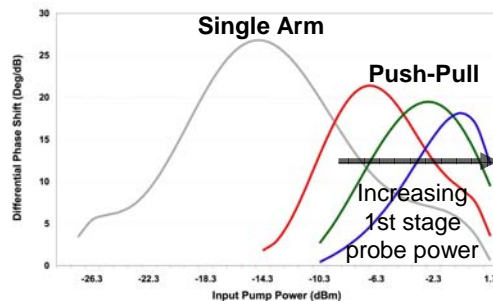
J. Summers, et. Al. - OFC 2007



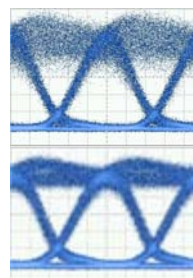
TIR Mirror



Phase Measurements

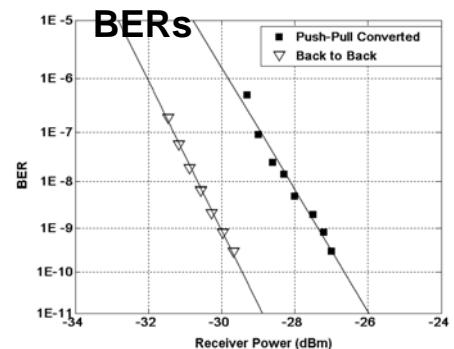


Eye Diagrams



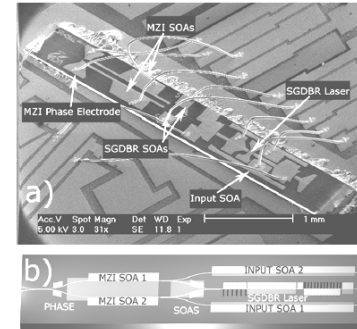
Single Arm
-large phase swing
-poor noise (noise floor)

Push-Pull
-full π phase swing
-improved noise

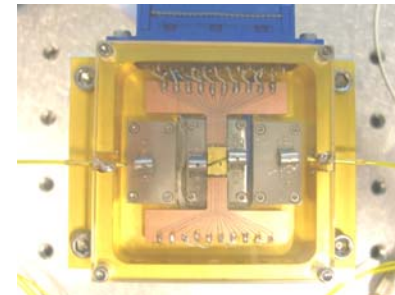


Materials-Device-Function-System

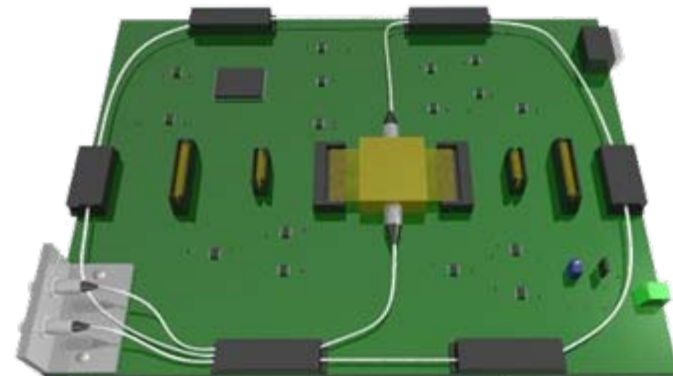
- 1st generation: Feb. '04
 - Chip-on-carrier 2.5Gbps wavelength tunable all-optical wavelength converters sent to MIT-LL.



- 2nd generation: Aug. '05
 - Packaged 2.5Gbps T-AOWCs sent to MIT-LL.

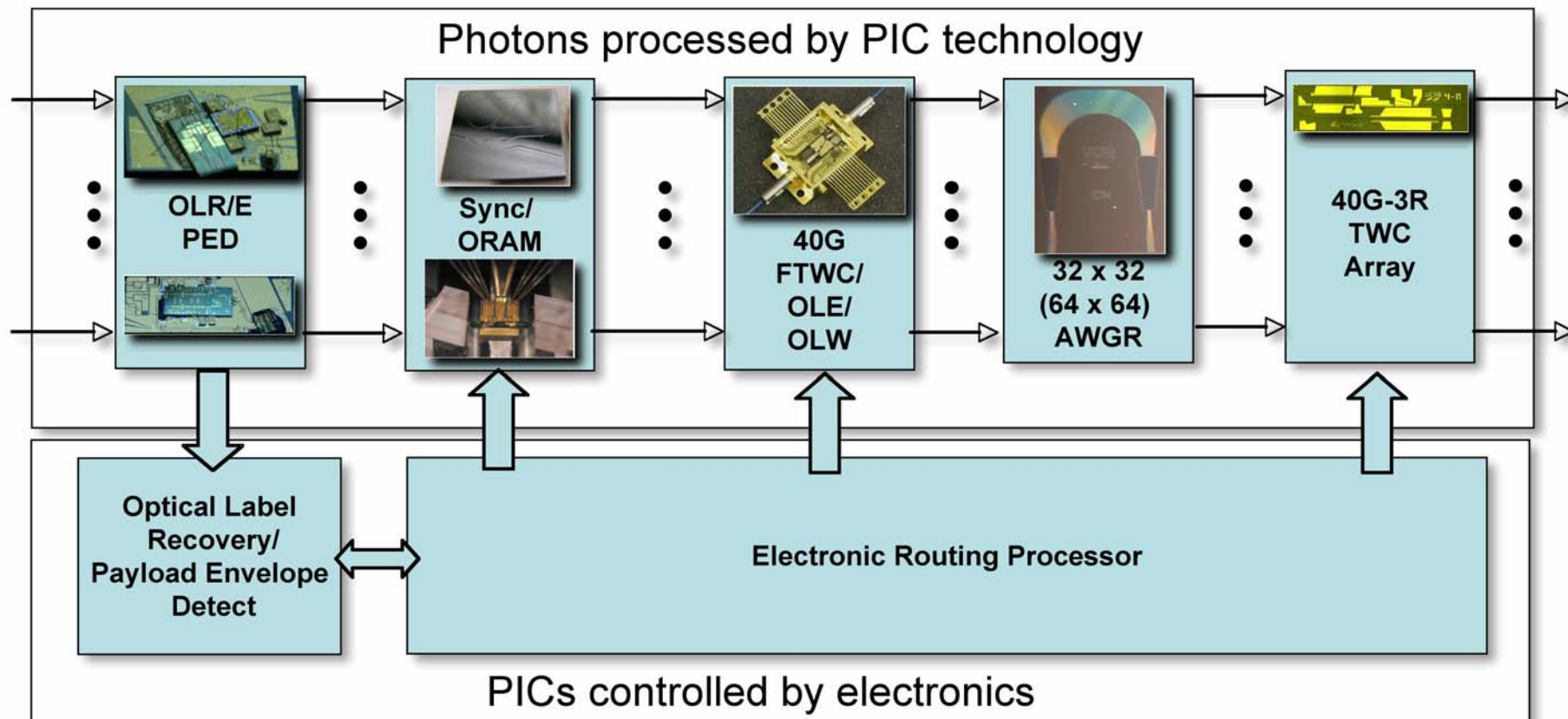


- 3rd generation: Dec. '05 - Jan. '06
 - (4) x T-AOWCs packaged and integrated on control circuit boards installed on in-flight demo.

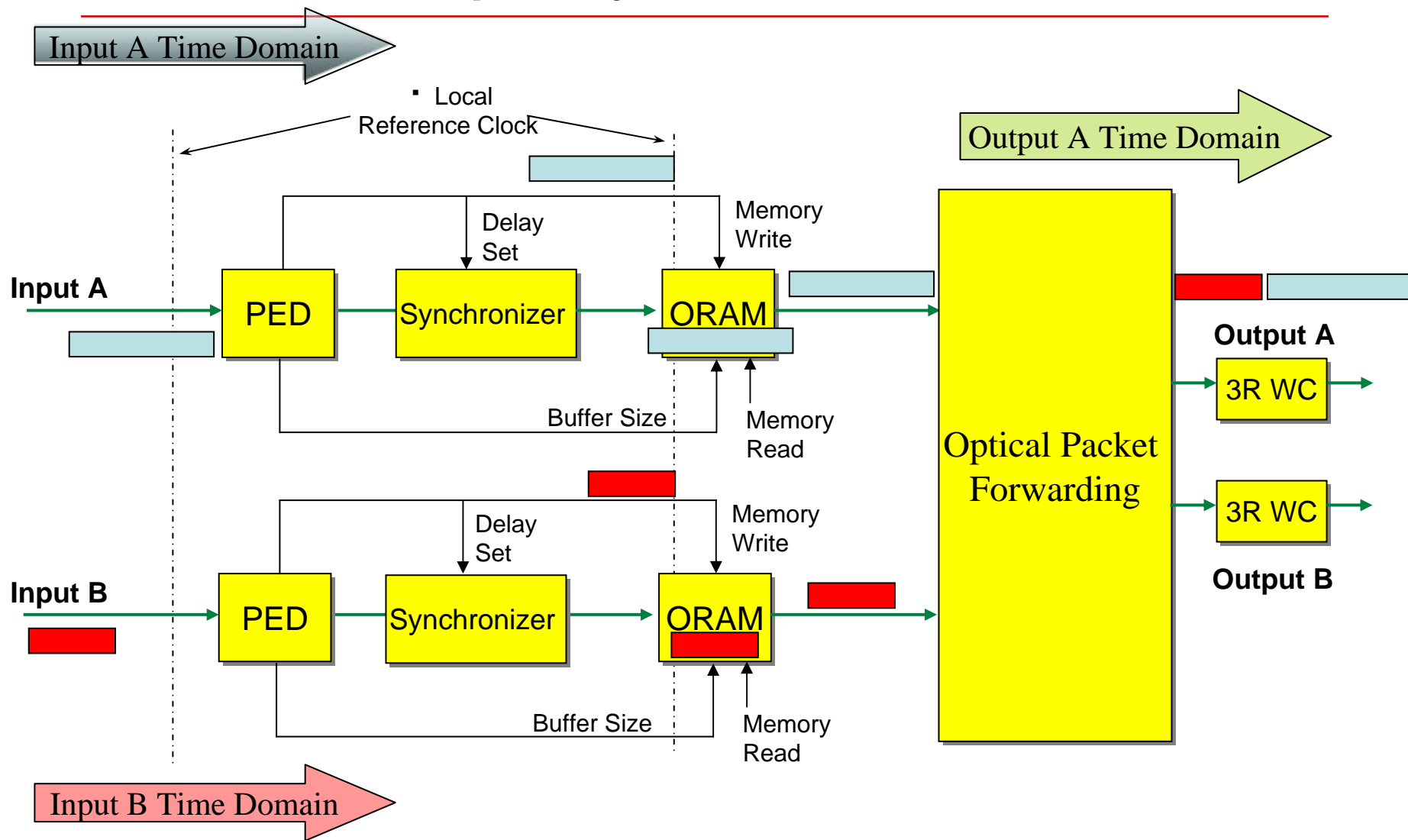


LASOR Optical Packet Router Linecard

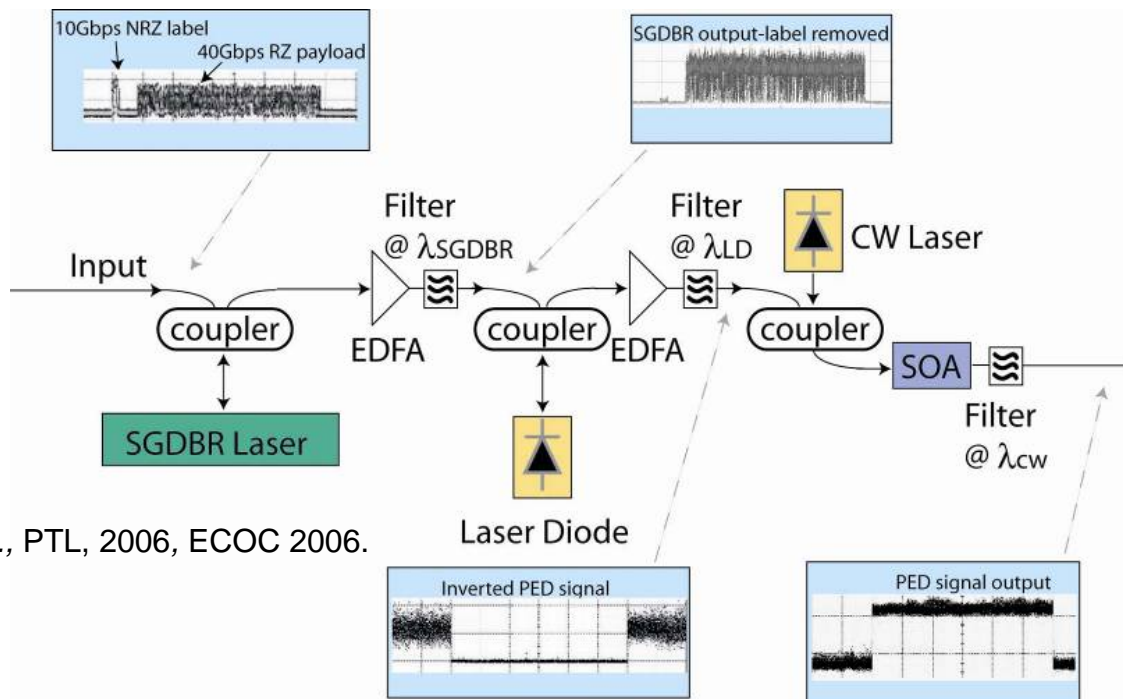
Pushing envelope on density and functionality of InP and Silicon Photonics



Optically Buffered ODR

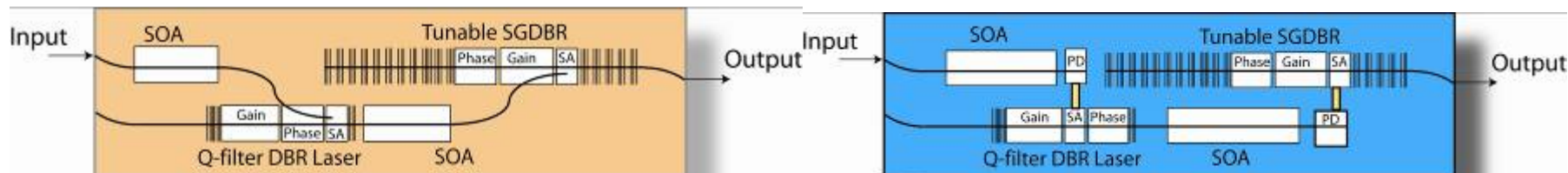


All-Optical PED



Ref: Koch *et al.*, PTL, 2006, ECOC 2006.

Integrated all-optical PED: Compact, single component, low power consumption, Less expensive, low latency



All-Optical 3R Regeneration

*Goals

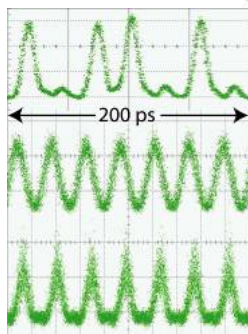
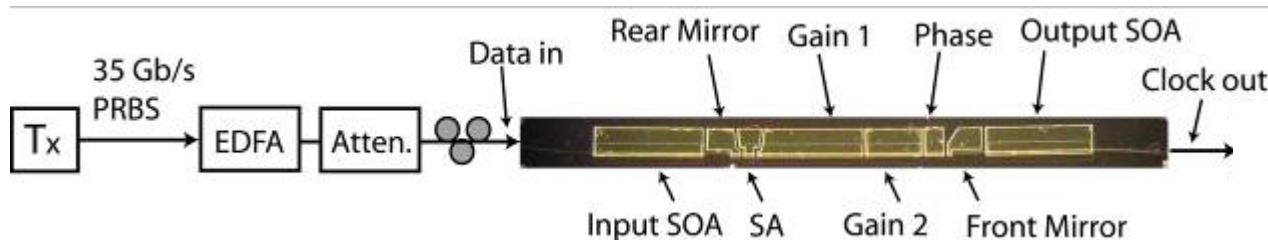
- *Precisely determine the repetition rate
- *Very high quality pulse reshaping and re-timing
- *integrated all-optical 3R regenerator

*Approach

- *Integrated Mode Locked Lasers with optical gates
- *Short, transform limited pulses
- *Very high extinction ratios
- *High output powers possible
- *Integrate MLLs with other components

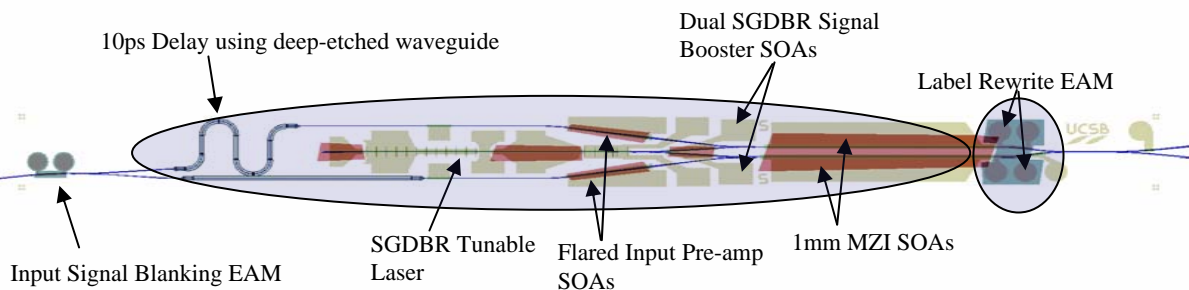


Clock Recovery with tunable output pulsewidth



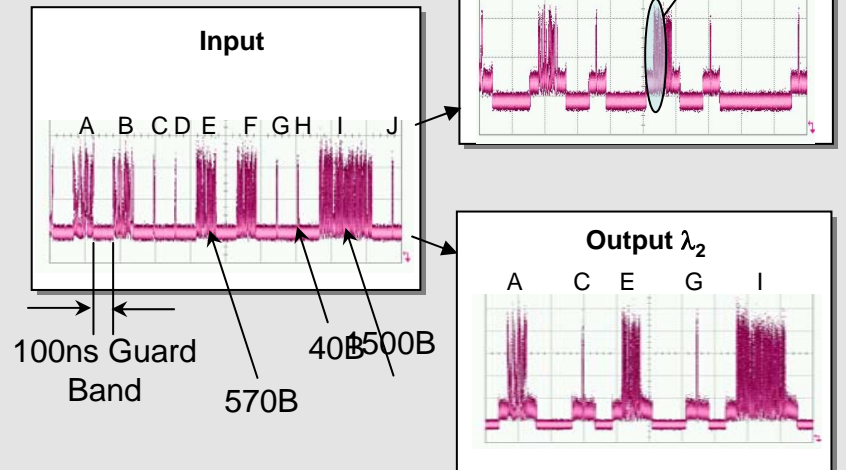
Ref: Koch et al. OFC 2007

PFC Packet λ -Conversion and OH Re-Write

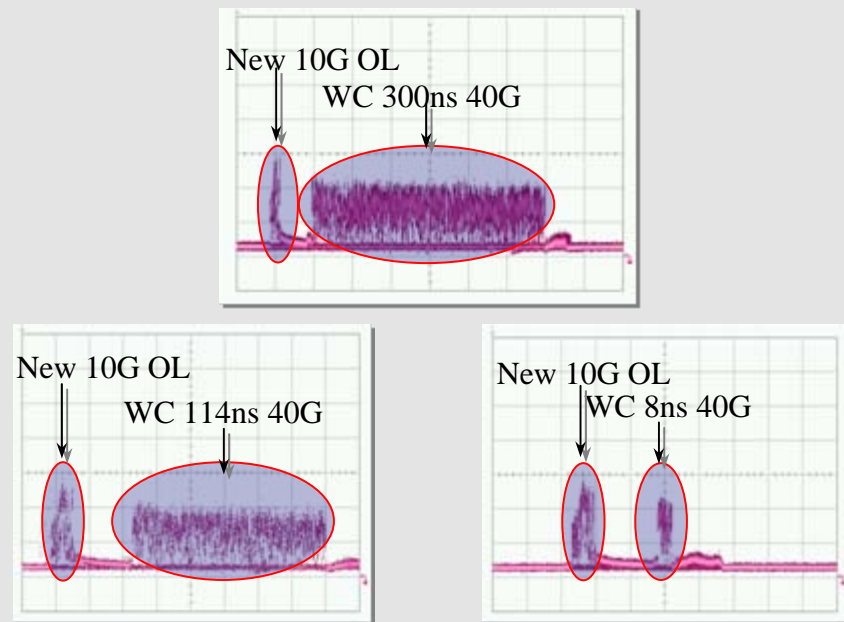


Variable Length Packets and Dynamic Forwarding + 100ns Guard Band

iMix 7:4:1 -> 40B:570B:1500B

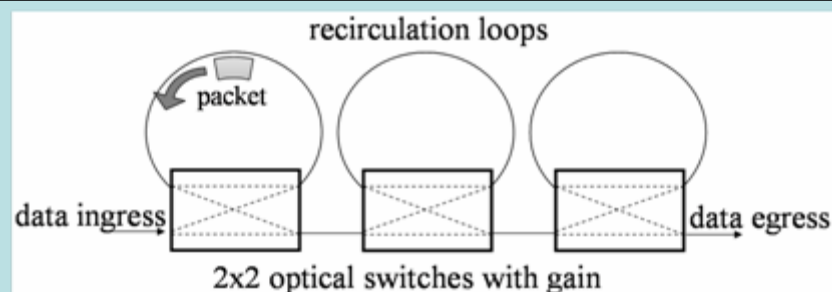


10G Optical Header Re-Write



Optical Buffer (ORAM)

- * Recirculating buffers for on-chip, integrated optical packet buffer with dynamic control of storage time and random read.



- * Hybrid buffers are designed to combine the fast switching available with InGaAsP-based photonic chips and the low propagation loss available with silica waveguides.

- * Silica waveguides have been designed and fabricated. Testing shows loss of less than 0.02 dB/cm.

- * Recent device fabrication shows good results on improved design features such as spot size converters and 90° bends, however out-sourced material regrowth created contamination which limited performance.

- * InGaAsP gate matrix switches were designed, fabricated, and tested. Error-free performance was shown with negligible power penalty. [Burmeister, *Photon. Technol. Lett.*, vol. 18, no. 1, 2006].

Chip Level 2x2 Optically Buffered ODR

QuickTime™ and a
decompressor
are needed to see this picture.