Optical Techniques For Circuits And Packet-Based Networking

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Technology Push and Integration Trends

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.
First Generation DWDM Optical Networks: Point-to-Point Transmission Links

- WDM Optical Fiber
- DeMux
- Optoelectronic Interface
- Framing, synchronization, switching, multiplexing, error correction and more, handled in electronics
- Router, Digital Crossconnect, SONET Crossconnect, SONET ADM
- Mux
- WDM Optical Fiber

SONET LTE
SONET does not scale well in DWDM ring networks
- Increased hardware complexity, cost, power dissipation
- Deployment and configuration issues
Optical Circuit Switched WDM

- Digital Cross-connect
- LTE
- OE Interface

Optical Fiber

- OE Interface
- LTE
- Digital Cross-connect

Optical Fiber

e.g. SONET becomes a service of the optical layer

Photonic Crossconnects or ROADM (Raman Optical Add/Drop Multiplexer)
Optical Network Evolution

DWDM Connected Routers

Lightpath Switched
DWDM over PXC

Electronic Router

Photonic Crossconnect

Optical Packet Router

Logical Connection

DWDM Connection
Optical Switch Technology
Switching Speed and Port Count

Switching Speed

- 10 ms
- 10 µs
- 10 ns

Number of Ports/Channels

- 10
- 100
- 1000

Optical Switch Technology

- MEMS Optical
- Thermooptic
- AOTF
- Liquid Crystal
- Tunable Wavelength
"λ"-Agile Optical Network Evolution

- Static λ
  - WDM Point-to-Point Links
  - Fixed Wavelength Add/Drop with Electronic Switching

- Static λ-Agile
  - WDM Optical Xconnects
  - Reconfigurable WDM Add/Drop

- Dynamic λ-Agile
  - Optical Burst Switching
  - Dynamic Circuit Switching
  - Optical Packet Switching

- Generations:
  - 1st Generation
  - 2nd Generation
  - 3rd Generation
  - 4th Generation
  - 5th Generation

Timeline:
- 1996
- 1999
- 2000
- 2001
- 2002
- 2003
- 2004
- 2005
- 2006
ROADMs and S-ROADMs (Scalable ROADM)

Service Interfaces (e.g. 10 GbE, SONET)

Grooming Transponders (e.g. 8 x 622Mbps to 10 Gbps)

Add more WDM fibers at input/output
Photonic Crossconnects

Fiber Bundled/Switched

Waveband Bundled/Switched

Wavelength Switched (blocking)

Wavelength Switched (nonblocking)
Wavelength Conversion
Space Switch
Technology Transition: Material-Device-Function-System

• 1st generation: Feb. ‘04
  • Chip-on-carrier 2.5Gbs 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.
FIND: Dynamic Optical Circuit Switching (DOCS)

FIND Project with N. McKeown, J. Bowers and B. Mukherjee
DOCS Network Example

- Optical TDM Frame
- Dynamic Optical Circuit Switch
- Dynamic Electrical Circuit Switch
- Packet Based Services

WB = Waveband
DOC = Dynamic Optical Circuit
DOCS Node

From Upstream Nodes

Optical Synchronizer

DeMux

Multiplexing

Optical Switch with Wavelength Conversion

From Electronic Circuit Layer

To Electronic Circuit Layer

Control Plane and Signaling Channel from Electronic Layer

To Downstream Nodes
DOCs Switch
Hybrid Silicon/InP Optics Implementation

Hybrid Si Laser: Bowers et. Al.
DOCs Testbed

Would like to try this on GENI
GENI BWG Optical Node and Optical Network Science Activities

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

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Research supported under DARPA/MTO DoD-N and CSWDM Program, and NSF FIND Program and GENI Planning Initiative.
Current Activities

- Backbone Node High Level Requirements (HLR)
  - 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
  - ROADMks
  - DOS (Digital Optical Switch)
  - deliverables, resources, components, dependencies, cost breakdown, structure, basis of cost, task schedule, baseline budget, contingency budget
  - MS Project
  - J. Barton, L. Garza, M. Mashanovitch, D. Casey, D. Blumenthal,
Backbone Substrate Model

Off-the-shelf commercial hardware, fixed WDM, framing, transport, add/drop
Optical bypass and fast sub-wavelength circuit switching
New optical technology hardware integration
Physical layer research: on how to move, switch and process light
Programmable framing and reconfigurable WDM

Control, management, network architecture, topology, applications, etc.
Framing, efficiency, connectivity, real time bandwidth, bandwidth abstraction and hierarchy
Network architecture, topology, etc.
Scalability, ultra-high connectivity, resource sharing, robustness, higher capacity with lower power and smaller footprint, optical functions
Robust transmission, higher bit rates, longer distances, richer modulation coding and formats
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.

 Once finished, non-changing document.
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
GENI BBN Functional Building Blocks

Packet Processor

Default
Programmable Framer

Null

Fast Circuit Switch

Wavelength Selective Switch

User (Research) Access at Multiple Layers
Proposed GENI Backbone Node Architecture

Programmable Router

10GE or POS Linecard
10GE or POS Linecard
Virtual Cut-Through Linecard

VSRI

FPGA

Connection to external networks

This linecard serves as a single channel (lambda) TDM switch that can cut through or add/drop sub-wavelength bandwidth without going into the router.

This box enables programming of different framing and transport protocols. It can be controlled by the router or a local or external network user. It is used to bridge protocols from external networks. The router or external network can also program a bypass state that makes this box transparent.

This box enables the node to access any of the wavelengths on the network via the ROADM and the Wavelength Tunable Interfaces (WTIs). The fast crossconnect also serves to proifice cut-through to wavelengths that are add/dropped from the ROADM. It can also pass through wavelengths intact to the router.

This box enables there to be more bandwidth on the network (e.g. lambdas, fibers) than in the node, allowing GENI to scale to a larger number of nodes and not require the electronics to match the total number of wavelengths or capacity of the network.

Out of Band Signaling and Control Channel

VSRI = Very Short Reach Interface
WTI = Wavelength Tunable Interface
--- = TDM switched channel

Short Reach 10G 1310nm

Fast Circuit Switch

Connection to external networks

ROADM

Fiber Switch (FS)

This box enables rollover capabilities and non-interfering physical layer research on GENI footprint.

Long Haul 10G 15xxnm

Fiber Switch (FS)

This box enables rollover capabilities and non-interfering physical layer research on GENI footprint.

Short Reach 10G 1310nm

10GE or POS Linecard
10GE or POS Linecard
10GE or POS Linecard
Virtual Cut-Through Linecard

Programmable Framers

VSRI

Fast Circuit Switch

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This box enables rollover capabilities and non-interfering physical layer research on GENI footprint.
Early Phase: Static Reconfigurable Optical Circuits

The simplest and nearest term optical switch technology utilizes circuit based optical add/drop multiplexers and optical crossconnects to configure the wavelengths as circuits between relatively arbitrary router interfaces across a network.

No longer does traffic need to pass through every router, rather the interface is connected to a traffic engineered wavelength (circuit), and that wavelength and its traffic can optically bypass pass through routers until terminated on the destination router.

This approach significantly saves on the amount of router hardware (power and space) needed to support a scalable network.

By making these optical add/drop multiplexers and switches reconfigurable the control plane can be used to set-up and re-route optical circuits on demand, order of minutes to hours to days.

To achieve this end goal, the management system becomes a complex entity that must keep track of all physical resources, connection patterns, route and state (node and line) tables, optical regeneration points as well as physical layer transport rules.
Beyond the reconfigurable optical circuit model is the dynamically switched optical bandwidth model enabled by a new generation of rapidly configurable switching technologies (e.g. rapid tunable lasers).

These new technologies can be used to realize packet add/drop multiplexers ways of dividing up the optical circuit bandwidth into subcircuit bandwidth.

This type of node will allow the GEENI processing and memory cycle transfers and requests to directly access the optical bandwidth on any available wavelength during a free time period.
Data Flow

1. How two packet processors communicate over Gigabit Ethernet. One packet processor creates a 1GE packet, the framer packs it into a null frame, which is part of a 1 gigabit TDM circuit, that is time division multiplexed onto a 10Gb/s wavelength.

2. Loopback at any layer: Data entering on a wavelength can be switched directly to another wavelength (without passing through any other layers) or can be switched at the TDM layer, or passed through the packet processor for packet level processing.

3. Connections to outside world: These can take place at any layer. For example, a non-packet processor node (e.g. commercial router, or another network) can connect directly to GENI through the programmable framer.
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
  - ROADM and reconfigurable OADMS to allocate wavelengths that are framing and bandwidth agnostic. Enable higher degree ROADM 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
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.