High Performance Communications Based on Dynamic Lightpaths: OMNInet and OptIPuter

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Partner, StarLight/STAR TAP, PI-OMNInet (www.icair.org/omninet)

JET Workshop on Optical Network Testbeds
National Science Foundation
Arlington, Va.

April 19, 2005
Introduction to iCAIR:

Accelerating Leading Edge Innovation and Enhanced Global Communications through Advanced Internet Technologies, in Partnership with the Global Community

- Creation and Early Implementation of Advanced Networking Technologies - The Next Generation Internet All Optical Networks, Terascale Networks
- Advanced Applications, Middleware, Large-Scale Infrastructure, NG Optical Networks and Testbeds, Public Policy Studies and Forums Related to NG Networks
Forum Issues

• Optical Network Testbed Attributes
• Research Goals
• Topology
• Equipment
• Schedule
• Current Status
• Thoughts on Major Considerations/Issues for JET Member Plans for Network Evolution
  – Observe ONT Results
  – Follow the Lightpaths
Designing a New Communications Architecture

- Multiple vs One Network
- Core Infrastructure: a Distributed Optical Infrastructure, Not a Traditional Network
- Distributed vs Centralized Control
- Distributed vs Centralized Management
- Elimination of Traditional Hierarchy
- Provide for Transparency
- Utilize All Layers vs L3 Only
- Utilize Potential of Advanced Optic
- Timeline for Implementation Began Several Years Ago
The Move to Data-Intensive Science & Engineering-e-Science Community Resources

Source: Larry Smarr
Perspective: Segmented Bandwidth Requirements

A. Lightweight users, browsing, mailing, home use
   – Need full Internet routing, one to many
B. Business applications, multicast, streaming, VPNs, mostly LAN
   – Need VPN services and full Internet routing, several to several + uplink
C. Special scientific applications, computing, data grids, virtual presence
   – Need very fat pipes, limited multiple virtual organizations, few to few

ΣA ≈ 20 Gb/s
ΣB ≈ 40 Gb/s
ΣC >> 100 Gb/s

Courtesy of Cees de Laat, Univ of Amsterdam
Invisible Nodes, Elements, Hierarchical, Centrally Controlled, Fairly Static

Limited Functionality, Flexibility

Traditional Provider Services: Invisible, Static Resources, Centralized Management

Distributed Device, Dynamic Services, Visible & Accessible Resources, Integrated As Required By Apps

Unlimited Functionality, Flexibility

Ref: OptIPuter Backplane Project, UCLP
Creation of Application Optical VPNs

Direct connect bypasses campus firewall

Source: Bill St. Arnaud
Lightpath Data Channels Within Fiber

- Data Over Light – Technologies That Enable *Dynamic* vs Static Lightpaths

Dynamic DWDM With Sophisticated Signaling and Control
Prototyping The Global Lambda Grid in Chicago: A Photonic-Switched Experimental Network of Light Paths
Lightwave Networking

- Production1 (Common)
- Production2 (Advanced)
- Experimental1 (General)
- Experimental2 (Specialized)
- Basic Research

Eg, Experimental2 Could Be Provisioned From Remote Instruments In Other Countries Directly to University Labs – Finally, Separate Networks On the Same Infrastructure!
Clusters

Dynamically Allocated Lightpaths

Switch Fabrics

Physical Monitoring

Apps

Multi-leveled Architecture

Directly Integrating Network And Application!

CONTROL PLANE

NEW!
Multiwavelength Optical Amplifier

IEEE 802.3 LAN PHY Interface, eg, 15xx nm

10GE serial

Multiwavelength Fiber

Multiple λ Per Fiber

DWDM Links

Multiwavelength Optical Amplifier

Power Spectral Density Processor, Source + Measured PSD

Multiple Optical Impairment Issues, Including Accumulations

Optical, λ Monitors, for Wavelength Precision, etc.

Computer Clusters Each Node = 1GE

Multi 10s, 100s, 1000s of Nodes

Near Term Potential for 10 G Elec. to BP
Longer Term Potential for Driving Light to BP via Si, New Polymers
Lambda Routing:
- Topology discovery, DB of physical links
- Create new path, optimize path selection
- Traffic engineering
- Constraint-based routing
- O-UNI interworking and control integration
- Path selection, protection/restoration tool - GMPLS

GMPLS Tools (with CR-LDP)
- LP Signaling for I-NNI
- Attribute Designation, eg Uni, Bi directional
- LP Labeling
- Link Group designations

OSM
- System Manager
  - Discovery
  - Config
  - Communicate
  - Interlink
  - Stop/Start Module
  - Resource Balance
  - Interface Adjustments

Data Plane
- Physical Processing Monitoring and Adjustment
  - Resource
  - Resource
  - Resource
  - Resource
  - Resource

Control Channel monitoring, physical fault detection, isolation, adjustment, connection validation etc.
Optical Layer Control Plane

Client Layer Control Plane

Client Controller -> Controller -> Controller -> Controller -> Controller

UNI

Client Device

CI

CI

CI

Optical Layer Control Plane

Controller

I-UNI

Client Layer Traffic Plane

Optical Layer – Switched Traffic Plane

Traffic Plane

iCAIR
New: Intelligent Application Signaling

IClient Layer Control Plane: Communications Service Layer
Service Layer, Policy Based Access Control, Client Message Receiver, Signal Transmission, Data Plane Controller, Optical Layer Control Plane
Data Plane Monitor

Optical Layer – Switched Traffic (Data) Plane
Multiservice: Unicast, BiDirectional, Multicast, Burst Switching

* Also Control Signaling, et al
Example Control Plane Signaling Functions

- Multi-Dimensional Signal Processing (Distributed)
- Signal Processing From Clients, e.g., Application, Systems, Device, Including Ad Hoc Demand for Resources
- Signalling ↔ Management Plane, e.g., Provisioning, Restoration
- Signally ↔ Resource Management, Including Resource Discovery, Scheduling/Reservation (IETF RSVP Extensions), Resource Contention Resolution
- Lightpath Provisioning (E2E), Deletion, Characterization
  - Via Signaling to Device Interfaces, e.g., Optical Switch Configuration with T1, GMPLS, et al
- Data Plane Signal Processing, e.g., Resource Advertisements
- Signaling ↔ Data Plane, e.g., Wavelength Assignment, Wavelength Routing
- Signaling ↔ Data Plane Management Systems
- Optimization Signaling ↔ IETF Extensions for OSPF for Optical Routing
- Et al
- Implications for Signaling Related to Optical Packet Switching
OMNIInet
The Metro Area OOO Tesbed

10 Gb Lambdas

Sheridan (3)

West Taylor (1)

Federal (5)

LakeShore (4)
OMNInet Technology Trial: January 2002-05

- Four-site Chicago network world’s first 10GE dynamic DWDM based service trial! SONET – Free Zone - individually addressable wavelengths, Step Toward G. 709, and beyond
- A advanced photonic based test bed for all-optical switching and advanced high-speed services
- Partners: SBC, Nortel, iCAIR at Northwestern, EVL, CANARIE, ANL
OMNInet Network Configuration

- 8x8x8\(\lambda\) Scalable photonic switch
- Trunk side – 10 G WDM
- OFA on all trunks

**W Taylor**

- PP 8600
- 10/100/10 GE
- Optera 5200 OFA

**S. Federal**

- PP 8600
- 10/100/10 GE
- Optera 5200 OFA

**Lake Shore**

- PP 8600
- 10/100/10 GE
- Optera Metro 5200 OFA

**Sheridan**

- PP 8600
- 10/100/10 GE
- Optera 5200 OFA

**DOT Clusters**

**CAMPUS FIBER (16)**

**CAMPUS FIBER (4)**

**EVL/UIUC OMS200**

**LAG/UIUC OMS200**

**INITIAL CONFIG: 10 LAMBDAS (ALL GIGE)**

**NWUEN-1**

**NWUEN-2**

**NWUEN-3**

**NWUEN-4**

**NWUEN-5**

**NWUEN-6**

**NWUEN-7**

**NWUEN-8**

**NWUEN-9**

**Fiber in use**

**Fiber not in use**

**StarLight Interconnect with other research networks**

**TECH/NU-E OMS200**

**Fiber**

<table>
<thead>
<tr>
<th>NWUEN Link</th>
<th>Span Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1*</td>
<td>35.3 KM</td>
</tr>
<tr>
<td>2</td>
<td>10.3 MI</td>
</tr>
<tr>
<td>3*</td>
<td>12.4 MI</td>
</tr>
<tr>
<td>4</td>
<td>7.2 MI</td>
</tr>
<tr>
<td>5</td>
<td>24.1 MI</td>
</tr>
<tr>
<td>6</td>
<td>24.1 MI</td>
</tr>
<tr>
<td>7*</td>
<td>24.9 MI</td>
</tr>
<tr>
<td>8</td>
<td>6.7 MI</td>
</tr>
<tr>
<td>9</td>
<td>5.3 MI</td>
</tr>
</tbody>
</table>

**1310 nm 10 GbE WAN PHY interfaces**

**10GE LAN PHY (Dec 03)**
Photonic Switch Architecture

- Wavelength plane architecture can connect any input signal of a specific wavelength to any output without wavelength translation.
- Could switch 8 instances of 8 wavelengths.
- Scalable Architecture - Larger Photonic Switch Node 640 x 640 wavelengths using the same architecture was developed.

Source: Kent Felski, Nortel
Overlay Management network (Typical Site & Inter-site Network)

- Centilian sw or Baystack 350T Hub
- Photonic Switch
- OPTera 5200 OFA & OTR
- Passport 8600
- Internet Connection (Lakeshore only)
- Firewall
- Ethernet VPN via OMNInet & PP8600
- Ethernet VPN via NU Inter-campus LAN
- Ethernet VPN via I-WIRE & PP8600
- 192.26.85.0/27
- 710 N. Lakeshore Dr.
- UIC (W.Taylor node)
- Evanstan (Sheridan node)
- 600 S. Federal (LGN CO LO)

• Hub and spoke network from 710 Lakeshore Dr.
Photonic Performance Subsystem

PPS Control Middleware

Photons Database

Switch Control

Management & OSC

Routing

Connection verification

Fault isolation

LOS

Path ID Corr.

Drivers/data translation

Relative code

Relative Tone

Relative Power

Relative Fiber power

Power measurement

Connection verification

Gain Controller

Transient compensator


λ. Leveling

Set point

AWG Temp. Control alg.

D/A

D/A

A/D

D/A

PhotoDetector

PhotoDetector

Switch

VOA

AWG

OFA

Source: Kent Felski, Nortel
Integrating Applications and Lightpaths
iCAIR Grid Clusters and OM5200 DWDM System

Leverone Hall Data Com Center

10GE WAN/LAN PHY to OMNInet

~20m

PP8600

OM5200

Technological Institute

DOT Clusters
For Telecom2003 Demo

~20m

OM5200

Up to 16xGE (SMF LX)

• The implementation is lambdas (unprotected).
• Installed shelf capacity and common equipment permits expansion of up to 16 lambdas through deployment of additional OCLD, and OCI modules.
• A fully expanded OM5200 system is capable of supporting 64 lambdas (unprotected) over the same 4-fiber span.
GRID Distributed Optical Testbed Components

- Cluster
- Advanced Photonics
- Environmental Conditioning, Power
- Cluster
Some Results

• Most Lightpaths Had Less Than 10 packets Lost Per Million
• For Stressed Lightpaths, 50 Packets Lost Per Million (~10^-10 BER)
• Note, However, That Some Measurements Were Limited
• In a Number of Tests, Large Scale Data Streams Were Transported For Many Hours With No Packet Losses (Measured).
• More Than 1000 Successful Lightpath Setup/Teardown Operations
• No Optical Component Failures - Several Electronic Component Failures
• Successful Demonstration of Two New Provider Services
• Successful Demonstration of Two New Internal Optical Transport Capabilities
• SONET/Router Not Required (Would Have Been a Performance Barrier)
• Great Grid Application Results – Extremely High Performance
• Created and Successfully Demonstrated, Multiple Times (at Metro level, Nationally and Internationally), a Basic Control/Management Plane Architectural Model, & Prototype Implementation
• Demonstrated the Utility of Dynamic Lightpath Switching to High Performance Applications
• Demonstrated the Potential of “Photonic Data Services”
Optical Dynamic Intelligent Network Services (ODIN)

- International Center for Advanced Internet Research
- Electronic Visualization Laboratory
- Laboratory for Advanced Computing, UIC

ODIN is a mechanism that allows global applications to use intelligent signaling to provision their own international lightpaths to optimize network-based resource discovery and performance. First public demonstration was at iGRID2002 - interdomain application signaling for dynamically provisioned lightpaths.

iGrid 2002
United States – Set New World Record for Data Transport

Photonic Data Services

• Laboratory for Advanced Computing, UIC
• National Center for Data Mining, UIC
• International Center for Advanced Internet Research
• SURFnet, NetherLight

At iGRID2002 the LAC, NCDM and iCAIR demonstrated Photonic Data Services (PDS) and set a new data transit record, based on several new protocols designed for high performance optical networks

www.lac.uic.edu, www.icair.org
End-to-End Transfer Time

- File transfer request arrives: 0.5s
- ODIN Server Processing: 3.6s
- Path ID returned: 0.5s
- Network reconfiguration: 25s
- FTP setup time: 0.14s
- Data Transfer 20 GB: 174s
- Path Deallocation request: 0.3s
- ODIN Server Processing: 11s

File transfer done, path released.

Source: Tal Lavian, Fei Yeh
CERN/iCAIR/CalTech FAST Demo
Steven Low, Cheng Jin, David Wei
Caltech
DARPA DWDM-RAM Large Scale Data+Dynamic Lambdas – Demonstrated at GGF9 & SC2003

- HP-PPFS
- Data Intensive App2
- Data Intensive App3
- Data Intensive App4

- Grid Data Management Services
- Data Web Services
- Data Grid Services

- Grid L3-L7 OGSA Compliant

- Dynamic Path Services (ODIN, THOR, etc), OGSA Compliant, Soon WSRF

- Dynamic vLANs

- Dynamic Lightpaths

- Physical Processing Monitoring and Adjustment

New Control Plane And Management Plane Processes
SC2004 Demonstration: Control Challenge

Source: Tal Lavian, Thanks to Kees Neggers, Bill St. Arnaud
DOT and Illinois’ I-WIRE:
Distributed Cluster Computing

Research Areas
- Displays/VR
- Collaboration
- Rendering
- Applications
- Data Mining

Latency-Tolerant Algorithms
Interaction of SAN/LAN/WAN technologies
Clusters

Source: Charlie Catlett
OptIPuter

Dr. Larry Smarr (PI)
Director, California Institute for Telecommunications and Information Technologies
Harry E. Gruber Professor,
Dept. of Computer Science and Engineering
Jacobs School of Engineering, UCSD
Tom DeFanti, (PI)
Director, Electronic Visualization Laboratory, University of Illinois at Chicago,
Professor, University of Illinois at Chicago,
Maxine Brown (Co-PI and Program Manager)
Associate Director, Electronic Visualization Laboratory, University of Illinois at Chicago,
Associate Professor, University of Illinois at Chicago,
The OptIPuter Project –
Creating a LambdaGrid “Web” for Gigabyte Data Objects

• NSF Large Information Technology Research Proposal
  – Calit2 (UCSD and UCI) and UIC Lead Campuses—Larry Smarr PI
  – USC, SDSU, NW, Texas A&M, UvA, SARA Partnering Campuses
• Industrial Partners
  – IBM, Sun, Telcordia, Chiaro, Calient, Glimmerglass, Lucent
• $13.5 Million Over Five Years
• Optical IP Streams From Lab Clusters to Large Data Objects

NIH Biomedical Informatics Research Network

http://ncmir.ucsd.edu/gallery.html

NSF EarthScope and ORION

siovizcenter.ucsd.edu/library/gallery/shoot1/index.shtml
What is the OptIPuter?

- **Optical networking, Internet Protocol, Computer Storage, Processing and Visualization Technologies**
  - Dedicated Light-pipe (One or More 1-10 Gbps WAN Lambdas)
  - Links Linux Cluster End Points With 1-10 Gbps per Node
  - Clusters Optimized for Storage, Visualization, and Computing
  - Does NOT Require TCP Transport Layer Protocol
  - Exploring Both Intelligent Routers and Passive Switches

- **Applications Drivers:**
  - Interactive Collaborative Visualization of Large Remote Data Objects
    - Earth and Ocean Sciences
    - Biomedical Imaging

- **The OptIPuter Exploits a New World in Which the Central Architectural Element is Optical Networking, NOT Computers - Creating "SuperNetworks"**

Source: Larry Smarr
Today’s Aerial Imaging is >500,000 Times More Detailed than Landsat7

Source: Eric Frost, SDSU
USGS Images 10,000 Times More Data than Landsat7

Landsat7 Imagery
100 Foot Resolution
Draped on elevation data

New USGS Aerial Imagery At 1-Foot Resolution

Source: Electronic Visualization Lab, UIC
Earth and Planetary Sciences are an OptIPuter Large Data Object Visualization Driver.

EVL Varrier Autostereo 3D Image

SIO 18 Mpixel IBM OptIPuter Viz Cluster

SIO HIVE 3 Mpixel Panoram
OptIPuter JuxtaView Software for Viewing High Resolution Images on Tiled Displays

30 Million Pixel Display
NCMIR Lab UCSD

Source: David Lee, Jason Leigh, EVL, UIC
The Crisis Response Room of the Future

SHD Streaming TV -- Immersive Virtual Reality -- 100 Megapixel Displays
Source: Electronic Visualization Lab, UIC
Increasing Accuracy in Hurricane Forecasts
Ensemble Runs With Increased Resolution

5.75 Day Forecast of Hurricane Isidore

Source: Bill Putman, Bob Atlas, GFSC

InterCenter Networking is Bottleneck

Intense Rain-Bands
Resolved Eye Wall

Operational Forecast
Resolution of National Weather Service

Higher Resolution Research Forecast
NASA Goddard Using Ames Altix

Precip [inches/hr] : Sea Level Pressure [mb] : 1000 MB Winds [m/s]

2002 SEP 26 18:00Z
New OptIPuter Driver: Gigabit Fibers on the Ocean Floor
A Working Prototype Cyberinfrastructure for NSF’s ORION

www.neptune.washington.edu

- NSF ITR with Principal Investigators
  - John Orcutt & Larry Smarr - UCSD
  - John Delaney & Ed Lazowska – UW
  - Mark Abbott – OSU
- Collaborators at:
  - MBARI, WHOI, NCSA, UIC, CalPoly, UVic, CANARIE, Microsoft,

www.sccoos.org/

LOOKING (Laboratory for the Ocean Observatory Knowledge Integration Grid) –
Adding Web Services to LambdaGrids
## OptIPuter Architecture

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<th>OptIPuter Applications</th>
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<td>Security Models</td>
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<td>λ-configuration, Net Management</td>
<td></td>
</tr>
<tr>
<td>Physical Resources</td>
<td></td>
</tr>
</tbody>
</table>

Source: Andrew Chien, UCSD
OptIPuter Software Architect
OMNInet
The Metro Area OOO Tesbed

10 Gb Lambdas
Demo of Multi-Domain OptIPuter

Cluster

University of Illinois at Chicago

All-optical LAN

PDC

PIN

Cluster

All-optical LAN

PDC

PIN

StarLight (Chicago)

OC-192

NetherLight (Amsterdam)

All-optical LAN

BOD/AAA

Cluster

Cities of Chicago and Evanston

OMNInet All-optical MAN

GMPLS/ODIN

PIN

Cluster

Source: Oliver Yu, Eric He
OptIPuter End Nodes Are Smart Bit Buckets
i.e. Scalable Standards-Based Linux Clusters with Rocks & Globus

Building RockStar at SC2003

---

**Complete SW Install and HW Build**

- From Piles of Parts to Running Cluster in Under 2 Hours
- Computational Chemistry & Brain Image Segmentation Ran
- Included the NSF Middleware (NMI) R3 Release of Software

**Rocks is the 2004 Most Important Software Innovation**
HPCwire Reader's Choice and Editor’s Choice Awards

Source: Phil Papadopoulos, SDSC
Brain Imaging Collaboration -- UCSD & Osaka Univ. Using Real-Time Instrument Steering and HDTV

Most Powerful Electron Microscope in the World - Osaka, Japan

Southern California OptIPuter

Source: Mark Ellisman, UCSD
UCSD Campus LambdaStore Architecture

SIO Ocean Supercomputer

IBM Storage Cluster

Extreme switch with 2 ten gigabit uplinks

Streaming Microscope

Streaming Microscope
OptIPuter Scalable Display Systems

UIUC/NCSA
SIO
USGS EDC
UCI
TAMU
SARA
UIC/NCMIR
UIC
OptIPuter is Prototyping
The PC of 2010

- Terabits to the Desktop...

- 100 Megapixels Display
  - 55-Panel

- 1/3 Terabit/sec I/O
  - 30 x 10GE interfaces
  - Linked to OptIPuter

- 1/4 TeraFLOP

Source: Jason Leigh, Tom DeFanti, EVL@UIUC
OptIPuter Co-PIs
Scalable Adaptive Graphics Environment (SAGE) Required for Working in Display-Rich Environments

Information Must Be Able To Flexibly Move Around The Wall

AccessGrid Live video feeds

Volume Rendering

Remote sensing

High-resolution maps

3D surface rendering

Remote laptop

Source: Jason Leigh, UIC
OptIPuter is Expanding the Reach of its Education and Outreach Programs
NLR Will Provide an Experimental Network Infrastructure for U.S. Scientists & Researchers

“National LambdaRail” Partnership
Serves Very High-End Experimental and Research Applications
4 x 10Gb Wavelengths Initially
Capable of 40 x 10Gb wavelengths at Buildout

First Light
September 2004

For more information regarding NLR see http://www.nlr.net or contact info@nlr.net
Expanding the OptIPuter LambdaGrid

Seattle

StarLight

NASA Ames

SD

Goddard SFC

ORNL

Amsterdam
10GE OptIPuter CAVEWAVE
Helped Launch the National LambdaRail

Next Step: Coupling NASA Centers to NSF OptIPuter

Source: Tom DeFanti, OptIPuter co-PI
The OptIPuter Is Being Supported By StarLight – a Facility “By Researchers For Researchers”

StarLight is an experimental optical infrastructure and proving ground for network services optimized for high-performance applications GE+2.5+10GE

Exchange Soon:
Multiple 10GEs Over Optics – World’s “Largest” 10GE Exchange!

View from StarLight

Abbott Hall, Northwestern University’s Chicago downtown campus
STARPLANE
DWDM Backplane

Source: Cees de Laat
CdL
Timeframes

- 1999 - 2000 Initial Design Concepts
- 2001 Initial Dynamic Lightpath Testbed
- 2003 Enhancements at Various Levels, Demonstrations at GGF, SC2003
- 2005 Designs for GLIF Persistent Infrastructure, Plans for Demonstrations at iGRID 2005, SC2005
- 2006 Integration With Other Communication Modalities, Enhanced Management Modules
- 2007 Multi-Mode Integration
World of Tomorrow - 1939
Future Generation Computer Systems (FGCS)

Volume 19, Number 6  
August 2003

Special Issue on  
iGrid 2002  
September 24-26, 2002  
Amsterdam,  
The Netherlands

22 Refereed  
Application Papers!

Guest Editors Tom DeFanti,  
Maxine Brown and Cees de Laat

http://www.igrid2002.org  
http://www.elsevier.com/locate/future
Communications of the ACM (CACM)

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Special issue: Blueprint for the Future of High-Performance Networking

• Introduction, Maxine Brown (guest editor)
• TransLight: a global-scale LambdaGrid for e-science, Tom DeFanti, Cees de Laat, Joe Mambretti, Kees Neggers, Bill St. Arnaud
• Transport protocols for high performance, Aaron Falk, Ted Faber, Joseph Bannister, Andrew Chien, Bob Grossman, Jason Leigh
• Data integration in a bandwidth-rich world, Ian Foster, Robert Grossman
• The OptIPuter, Larry Smarr, Andrew Chien, Tom DeFanti, Jason Leigh, Philip Papadopoulos
• Data-intensive e-science frontier research, Harvey Newman, Mark Ellisman, John Orcutt

www.acm.org/cacm
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www.startap.net/starlight