OMNI.net: A Metropolitan 10Gb/s DWDM Photonic Switched Network Trial

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Agenda

- Rationale and Applications
- Network Architecture
- Photonic Switch Implementation
- Control Plane
- Results
- Research Projects
Optical Metro Network Initiative

• Partnership
  – Nortel Networks
  – SBC Communications
  – International Corporation for Advanced Internet Research (iCAIR)/Northwestern University

• Experimental metropolitan photonic network field trial

• 10Gb/s Ethernet WAN and LAN service over a wavelength-granularity photonic switched network

• G.ASON, GMPLS Control Plane
Services and Applications

- **Enhanced metro photonic services**
  - O-VPNs
  - Dial-a-lambda service
  - Router by-pass

- **Emerging applications**
  - Optical GRIDs
  - Storage on demand
  - Data Mining
  - 3D teleconferencing
  - Visualization
  - Large-Science Apps
Network Configuration

- 4 sites in Chicago
- 6 fiber spans
- 4 wavelength planes
- Partial mesh network

4 sites in Chicago:
- Site T
- Site F
- Site L
- Site S

Fiber spans:
- Site T to Site F: 7.6 km
- Site T to Site L: 12.3 km
- Site F to Site L: 7.4 km
- Site L to Site S: 7.2 km
- Site L to Site S: 24.6 km
- Site L to Site S: 24.8 km

Network Configuration:
- 4 sites in Chicago
- 6 fiber spans
- 4 wavelength planes
- Partial mesh network

Visualization Lab
Data Mining Lab
CA*Net 3
Starlight
Photonic Labs

= Glass-Thru Central Office
OMNInet Network Configuration-2004

- 8x8x8λ Scalable photonic switch
- Trunk side – 10G DWDM
- OFA on all trunks

- 10 GigE
- 10/100/ GigE
- 10/100/ GigE
- 10/100/ GigE
- 10/100/ GigE
- 10/100/ GigE
- 10/100/ GigE
- 10/100/ GigE
- 10/100/ GigE
- 10/100/ GigE

- Optical Line Terminal (OLT)
- Optical Line Terminator (OLT)
- Optical Line Terminator (OLT)
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- SBC Fiber

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<th>Span Length</th>
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* not in use

- 1310 nm 10 GigE
- 10 GigE LAN PHY (Apr 04)
- 10 GigE WAN PHY interfaces

- StarLight / Lakeshore Interconnect with other research networks

- TECH/NU-E OM5200
- LAC/UIUC OM5200
Fiber Infrastructure

- SBC metro G.652/SMF-28 single mode fiber
  - “Next pair” selected from installed fiber plant
  - Longest span ~25km
  - 2 to 5 Glass thru per span
- Span losses from 6dB to 13dB (1550nm)
  - 0.5dB/km to 1.2dB/km
- Characterization tests
  - ORL, PMD, CD, OTDR
DWDM Lightpaths

- C-band ITU-T grid 200GHz spacing
- 4 wavelengths installed in the test bed:
  - 1550.92 nm
  - 1552.52 nm
  - 1547.72 nm
  - 1549.32 nm
- Switch supports 8 wavelengths
- Per-wavelength power grooming enabled a mix of high and low performance TRx (FEC, Modulator Driver...)
- 24 possible light paths on each wavelength plane: 96 total
- Longest lightpath ~75 km
Optical Link Impairments

Built Into Transmission Margin
- Fiber Losses
- Chromatic dispersion
- Back reflections
- Polarization mode dispersion
- Nonlinear effects

Actively Controlled
- Electrical crosstalk
- Receiver noise
- Timing jitter
- Electric
- Sensitivity

- Optical power tolerance
- Modulator chirp
- Laser wavelength stability
- Laser relative intensity noise
- Electrical cross-talk
- Extinction ratio
- Back reflection effects
- Timing jitter

- Losses
  - Optical amplifier effects on OSNR
  - Amplifier Transient
  - DWDM filter shape
  - Optical crosstalk
  - Back reflections
  - Polarization-dependent loss
Link Budget

• Link budget is deterministic and computed to work in all 24 network configuration.
• Link loss diversity 6dB to 13dB
• Node loss diversity 6dB to 10dB
• Commercial optical amplifiers
  • pre-amp and/or post-amp configurations
  • 23dB constant-gain
• Minimum OSNR
  • 32dB for LAN interfaces (experimental hardware)
  • 24dB for WAN interfaces (product hardware)
• FEC RS(255, 239) implemented on WAN wavelengths
• Dispersion compensated on longest span (chirpy EML on experimental hardware)
Transmitter ID

• Power monitoring and signal tagging system implemented.
• Transmitter signal tagged with unique 100kHz - 400kHz AM tone.
• Tone sensing using simple photo-detection circuits and DSP-based analyzer.
• Tone power proportional to the optical power.
• Used to sense power and ID both muxed and single wavelength fibers.
• 0.1dB precision, 0.5dB accuracy.

Tone Modulation on data carrier (Exaggerated).
Node Configuration.

Client interfaces:
- 10/100
- Gigabit Ethernet

10 Gbps Transponder

1310nm Transponder

ITU-T C-band waves

Photonic Switch Node
- OPM & VOA
- 2-D MEMs switch
- λ mux/demux
- OFA

Passport 8600 Ethernet Switch/Router (Commercial and Experimental Interfaces)

OPTera Metro 5200

WAN

LAN

Inter-Node Fibers

Metro Amplifiers

PP8600 Switch Router

1310nm

LAN

10 Gbps Transponder

• OPM & VOA

• 2-D MEMs switch

• λ mux/demux

• OFA
Site Installation
Mosaic of node at Site F

- Overlay Management
- Network hub/switch
- OPTera 5200
- Optical Amplifier
- Passport 8600
- OPTera 5200
- Transponder
- Photonic Switch Node
- Node Controller and DSP
- Photonic Switch Node
- 10GE LAN Blades
- 10GE WAN Blade
- Power Inverter
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.
- Larger Photonic Switch Node 640 x 640 wavelengths using the same architecture was developed.
- Much more efficient switch architectures are subject of multiple patent applications
G.ASTN Control Plane with O-UNI

- Node T
- Node L
- Node S
- Node F

UNI control interface

Network Optical Link (Data Plane)

Access Optical Link

TCP/IP connectivity (Control Plane)

Photonic Switch (Routing Card)

Optical Service Client (or CPE)

Management or User Workstation

Proxy O-UNI-C Server

UNI Service I/F

O-UNI-N

WRP

WDP

OLMPP

SCP

Management or User Workstation
OMNInet Control Plane: Protocols & Interfaces

- **System configuration/maintenance**
  - Consolidated optical link/interface configuration
  - Support on-line static/dynamic link/interface provisioning
  - Module start/stop, memory and resource management
  - Configuration data storage

- **Wavelength Routing Protocol (WRP)**
  - Optical topology discovery and inventory of physical link resource
  - New path selection/optimization algorithm to support traffic engineering and constraint-based routing
  - O-UNI interworking & control integration
  - Integrated path selection and protection/restoration with WDP
  - O-VPN support

- **Wavelength Distribution Protocol (WDP)**
  - End-to-End, on-demand light path signaling for I-NNI
  - Bi-directional LSP
  - Optical Connection Admission Control (CAC)
  - Generalized label and wavelength label set
  - 1:1 & 1:N Light path restoration

- **Optical Link Management Protocol (OLMP)**
  - Control channel monitoring
  - TE link resource management
  - Optical link fault isolation
  - Verify dark fiber connectivity

- **O-UNI server**
  - Client register/de-register
  - TNA address resolution
  - VPN group auto discovery
  - On-demand light path creation/deletion
  - Light path status enquiry
 Results

- Network has been operating since 2001
- Most lightpaths have less than 10 packets lost per million (Measurement limited)
- Stressed lightpath 50 packets lost per million ($\sim 10^{-10}$ BER)
- More than 1000 lightpath setup/teardown operations
- No optical component failures
Summary

• Technology field trial
  • Photonic switched network
  • Highly managed photonic layer
  • Scalable photonic switch architecture
  • Standards-based control plane
  • For bandwidth intensive applications

• Network continues to operate as infrastructure for content networking research (DARPA DWDM-RAM project)
References to experiments using OMNInet

- Photonic TeraStream demonstration over OMNInet
- A Case for the Global Access to Large Distributed Data Sets using Data Webs Employing Photonic Data Services
- Distributed Optical Testbed (OMNInet provides one leg of the DOT)
  - [http://www.dotresearch.org/about.html](http://www.dotresearch.org/about.html)
- SABUL experiments over OMNInet
- Northwestern University Information Technology Annual Report - 2002 (pp14 & 17 refers)
  - [http://www.it.northwestern.edu/AR02/report.pdf](http://www.it.northwestern.edu/AR02/report.pdf)
- FAST TCP Experiments (see last 4-5 charts for OMNInet reference)
  - [FAST v3](http://www.rgrossman.com/pdf/sabul-hpdtp-11-02.pdf)
DWDM-RAM

- DARPA funded research project
- Architecture for data-intensive services
  - Manage extremely large sets of distributed data
  - Dynamic on-demand light path and “e-path” provisioning
  - Network resource scheduling
- Demonstrations
  - GGF9 (Chicago, Oct 2003)
  - Chicago, Jun 2004 (SUPERComm)
- Current research/experiment activity:
  - Multiple sequential service requests
  - File transfer performance measurements and metrics
  - Other transport protocols
Data Transmission Plane
Connection Control
Optical Control Plane
Data Path Control
Basic Data Transfer Service
Data Transfer Scheduler
Network Resource Service
Basic Network Resource Service
Network Resource Scheduler
Applications
External Services
Other Services
Processing Resource Service
Storage Resource Service
Data Center
Dynamic Optical Network
Data Transmission Plane
Data Transfer Service
Network Transfer Service
Applications
Basic Data Transfer Service
Data Transfer Scheduler
Network Resource Service
Basic Network Resource Service
Network Resource Scheduler
Data Path Control
Optical Control Plane
Connection Control
Data Center
External Services
Other Services
Processing Resource Service
Storage Resource Service
Dynamic Optical Network
Data Transmission Plane
Data Center
Data storage switch
End-to-end Transfer time (Not Optimized)

- File transfer request arrives
- ODIN Server Processing
- Path Allocation request
- Request Path Deallocation
- ODIN Server Processing
- Path ID returned
- Network reconfiguration
- FTP setup
- Data Transfer (10 GB)
- 464s
- Path setup: ~48.7s
- Data Transfer (10GB): ~464s
- Path Teardown: ~11.3s
DWDM
RAM
Data@LIGHTspeed