

OMNInet: 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**

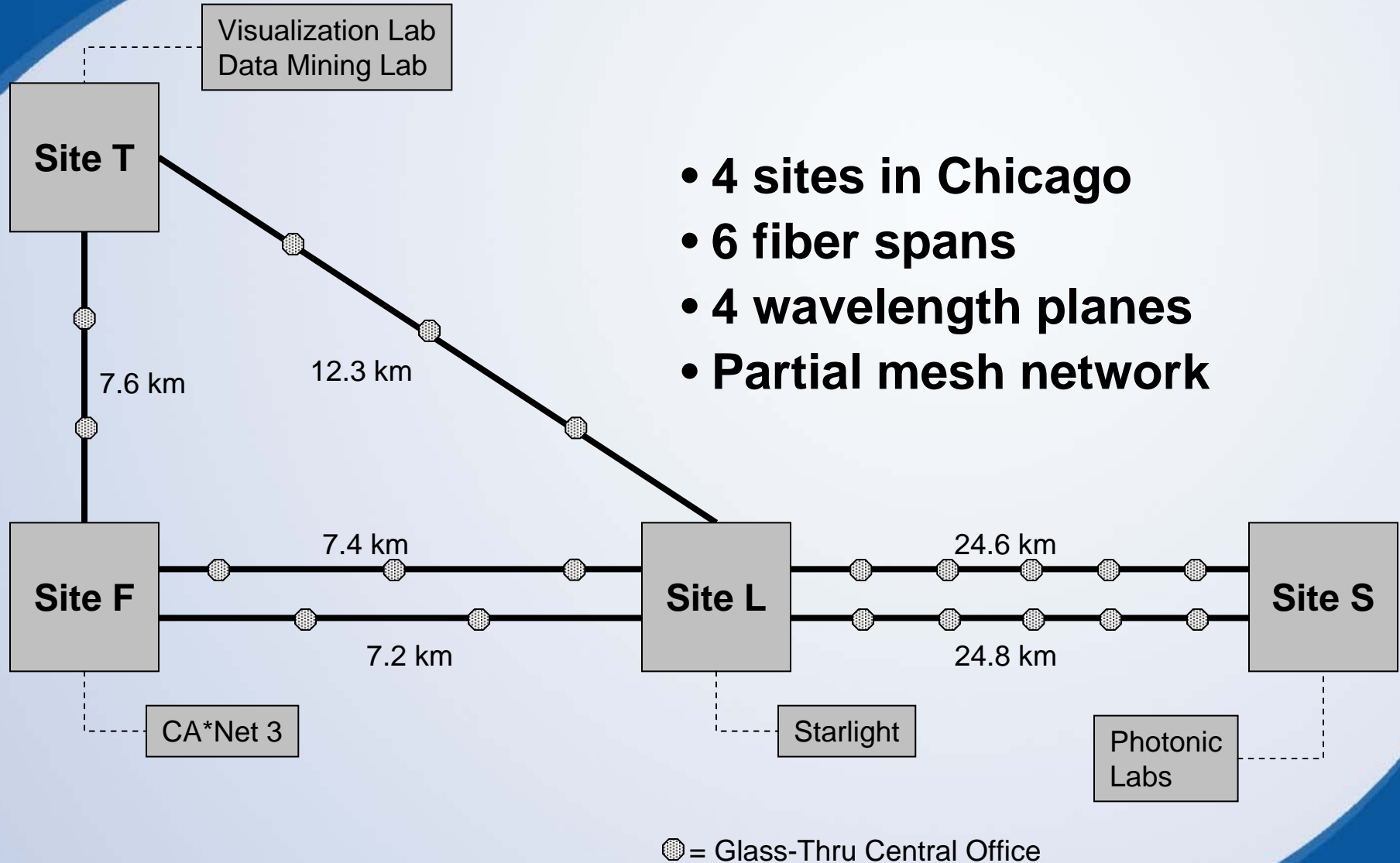
Services and Applications

- **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



3D Multi-Media
Virtual Design
3D Virtual Museum

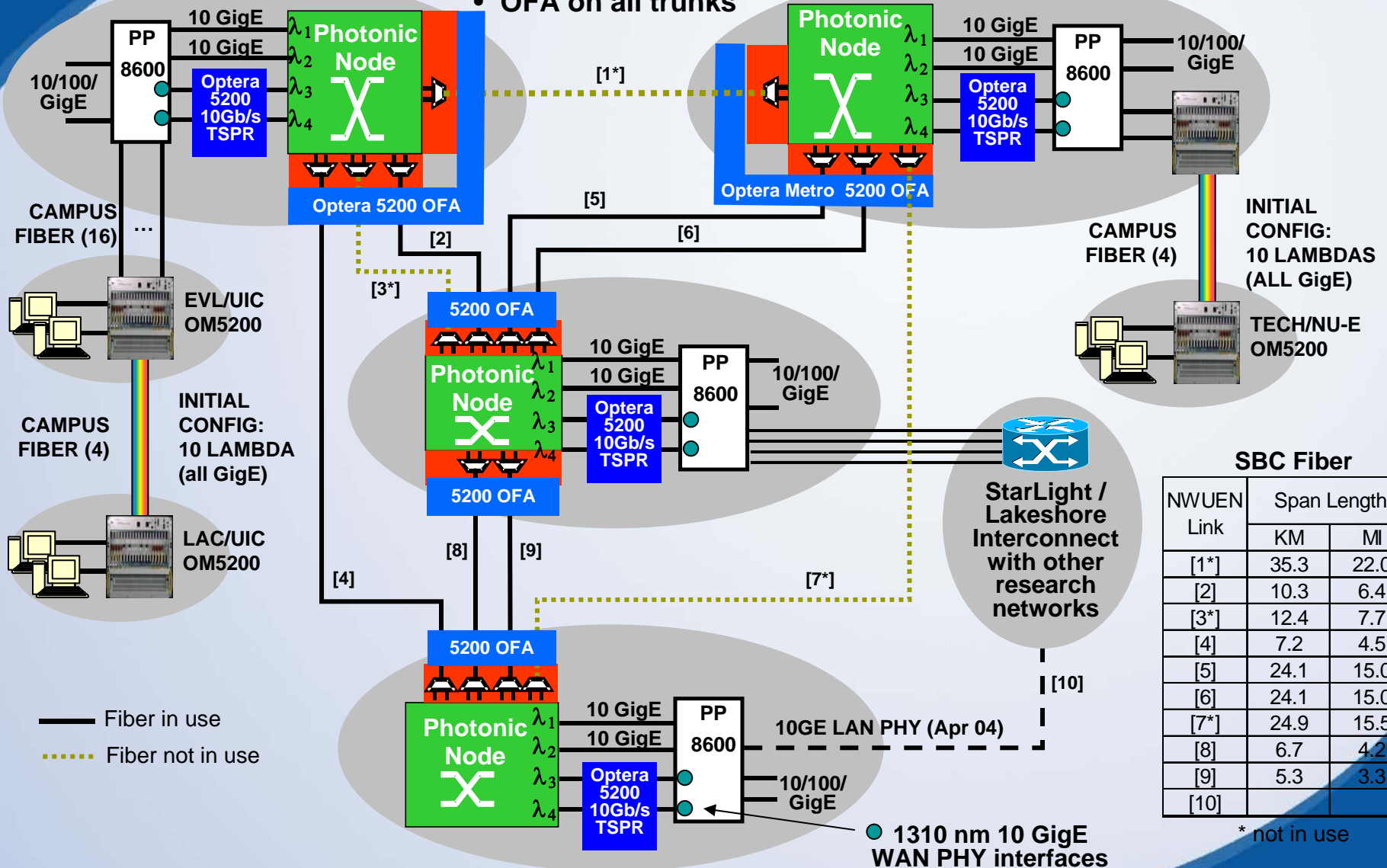
Network Configuration



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

OMNInet Network Configuration-2004

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



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**

**Actively
Controlled**

- Fiber Losses
- Chromatic dispersion
- Back reflections
- Polarization mode dispersion
- Nonlinear effects

- 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

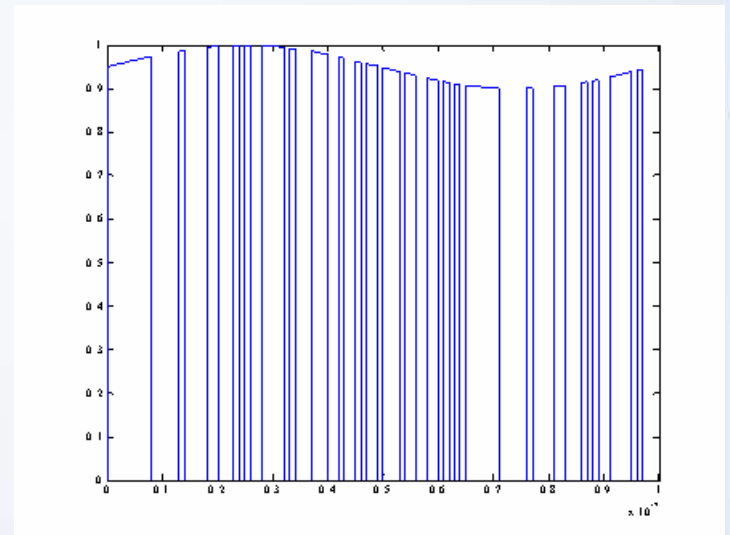
- Losses
- Optical amplifier effects on OSNR
- Amplifier Transient
- DWDM filter shape
- Optical crosstalk
- Back reflections
- Polarization-dependent loss

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)**

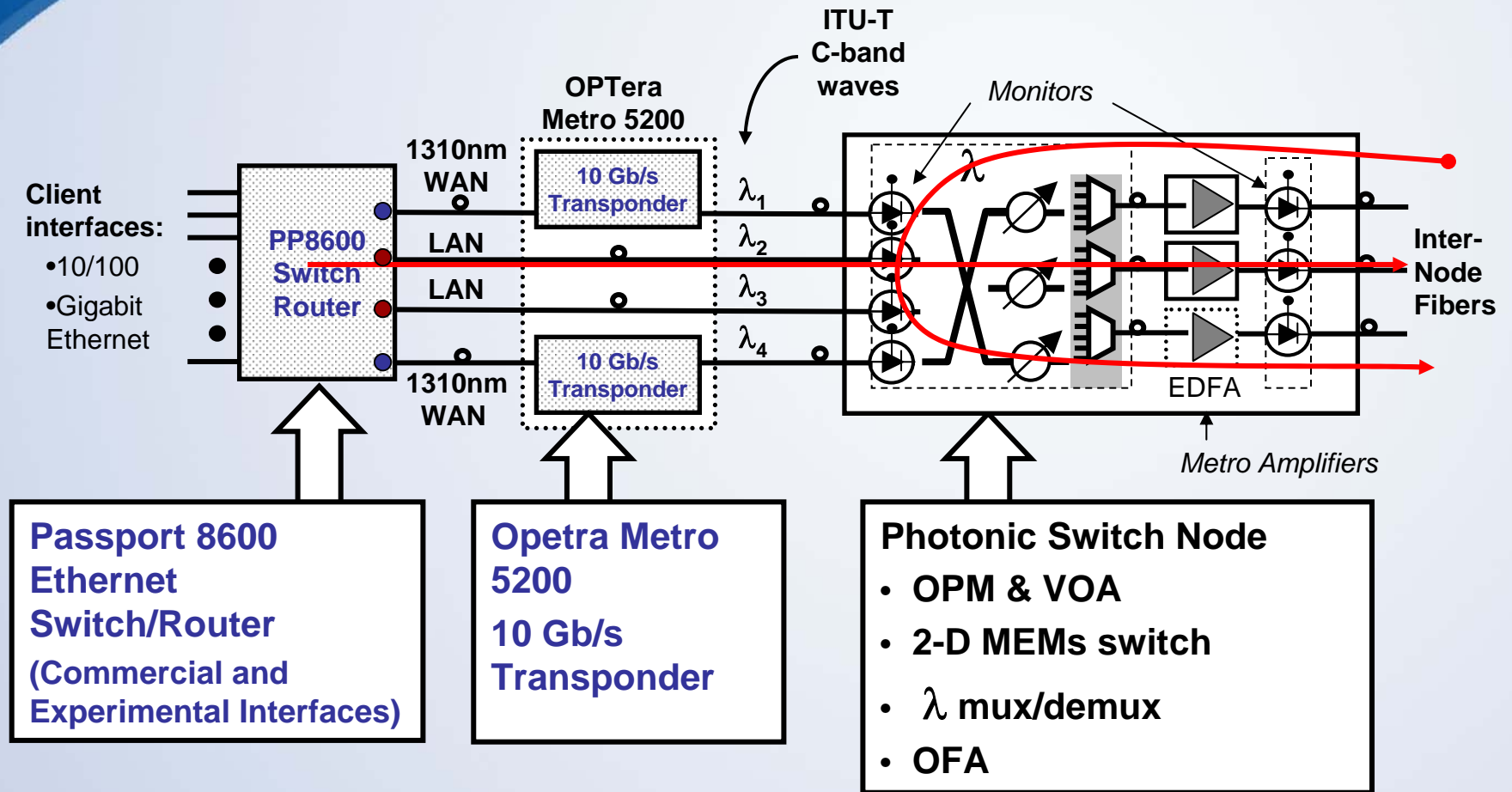
Transmitter ID

- 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.



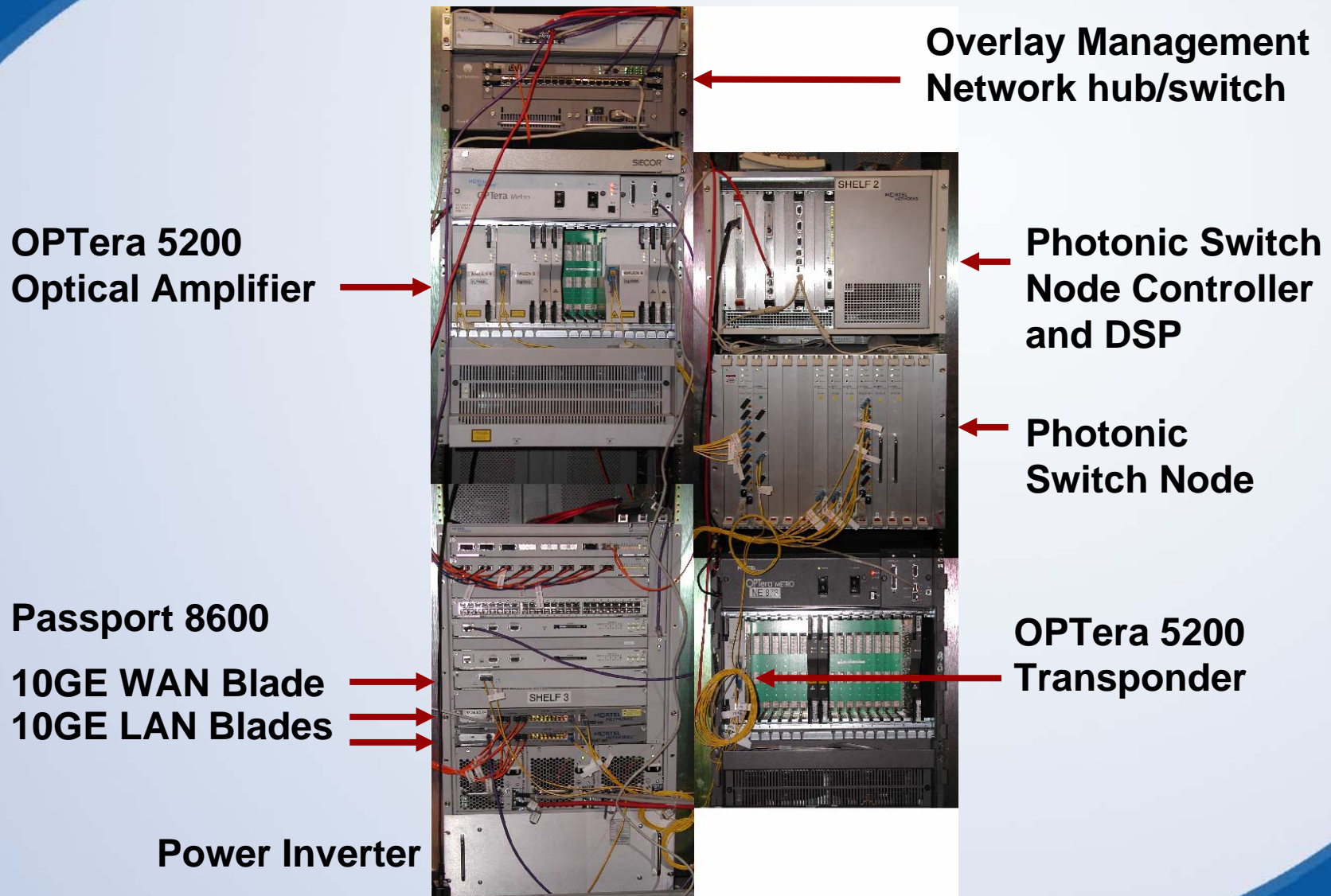
Tone Modulation on data carrier (Exaggerated).

Node Configuration.



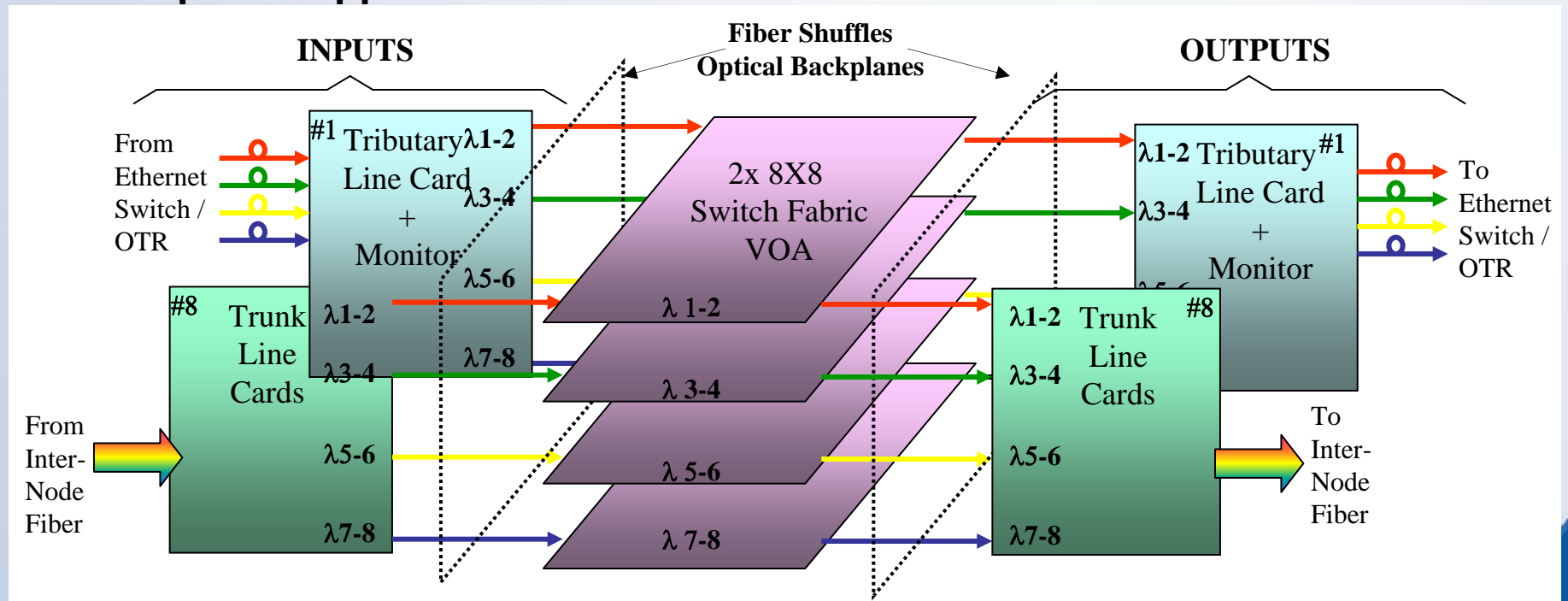
Site Installation

Mosaic of node at Site F

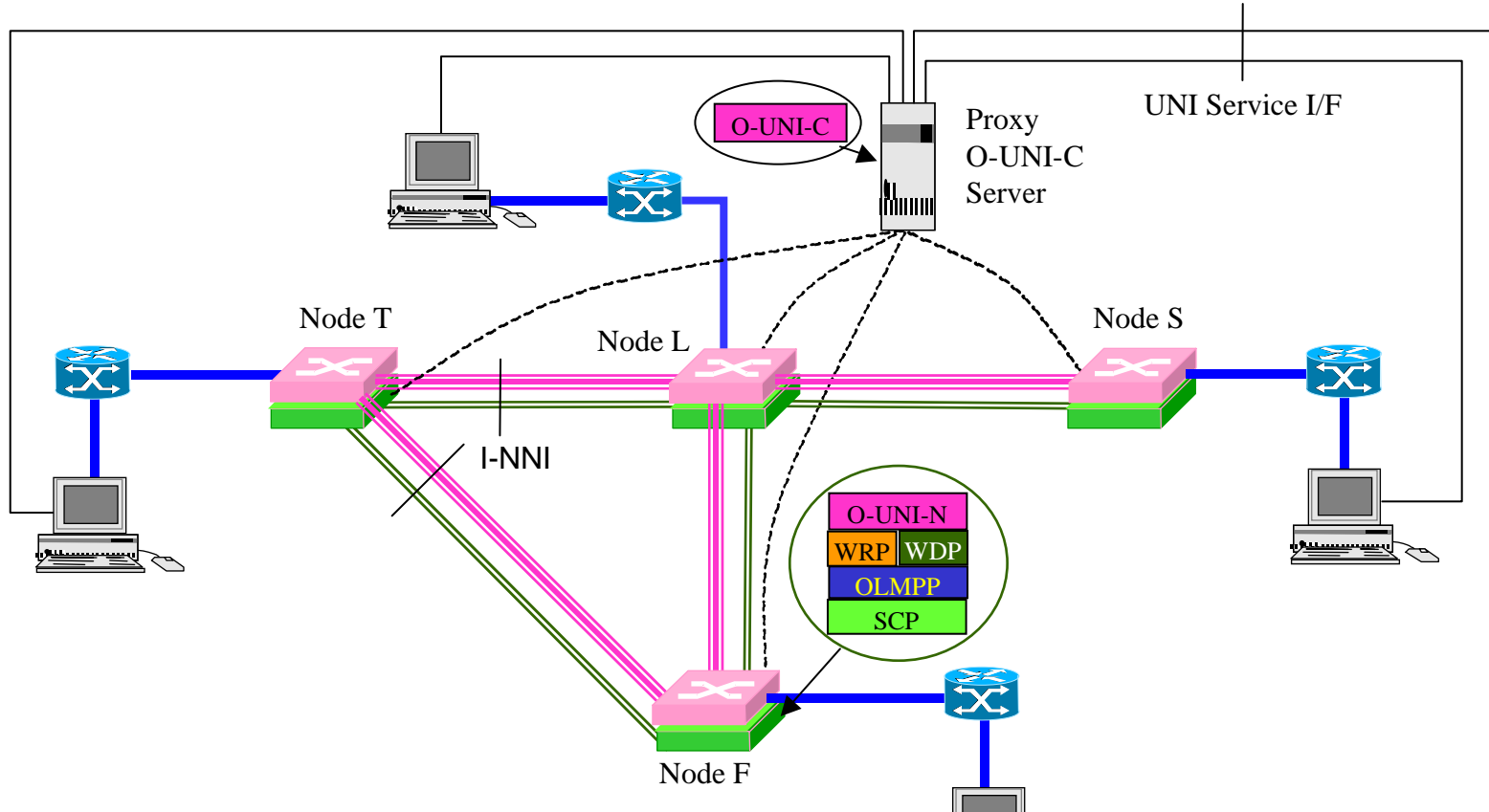




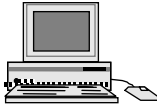
Photonic Switch Architecture

- 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



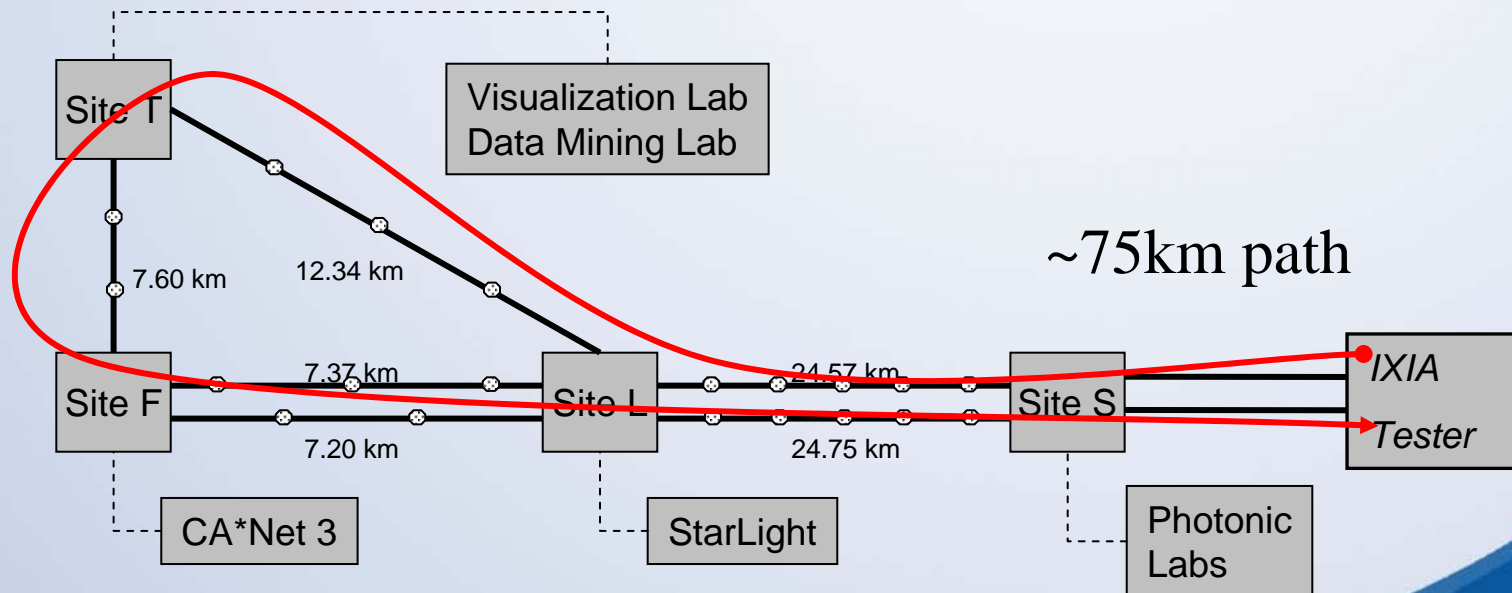
- UNI control interface
- ==== Network Optical Link (Data Plane)
- ==== Access Optical Link
- ==== TCP/IP connectivity (Control Plane)
-  Photonic Switch (Routing Card)
-  Optical Service Client (or CPE)
-  Management or User Workstation

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)**

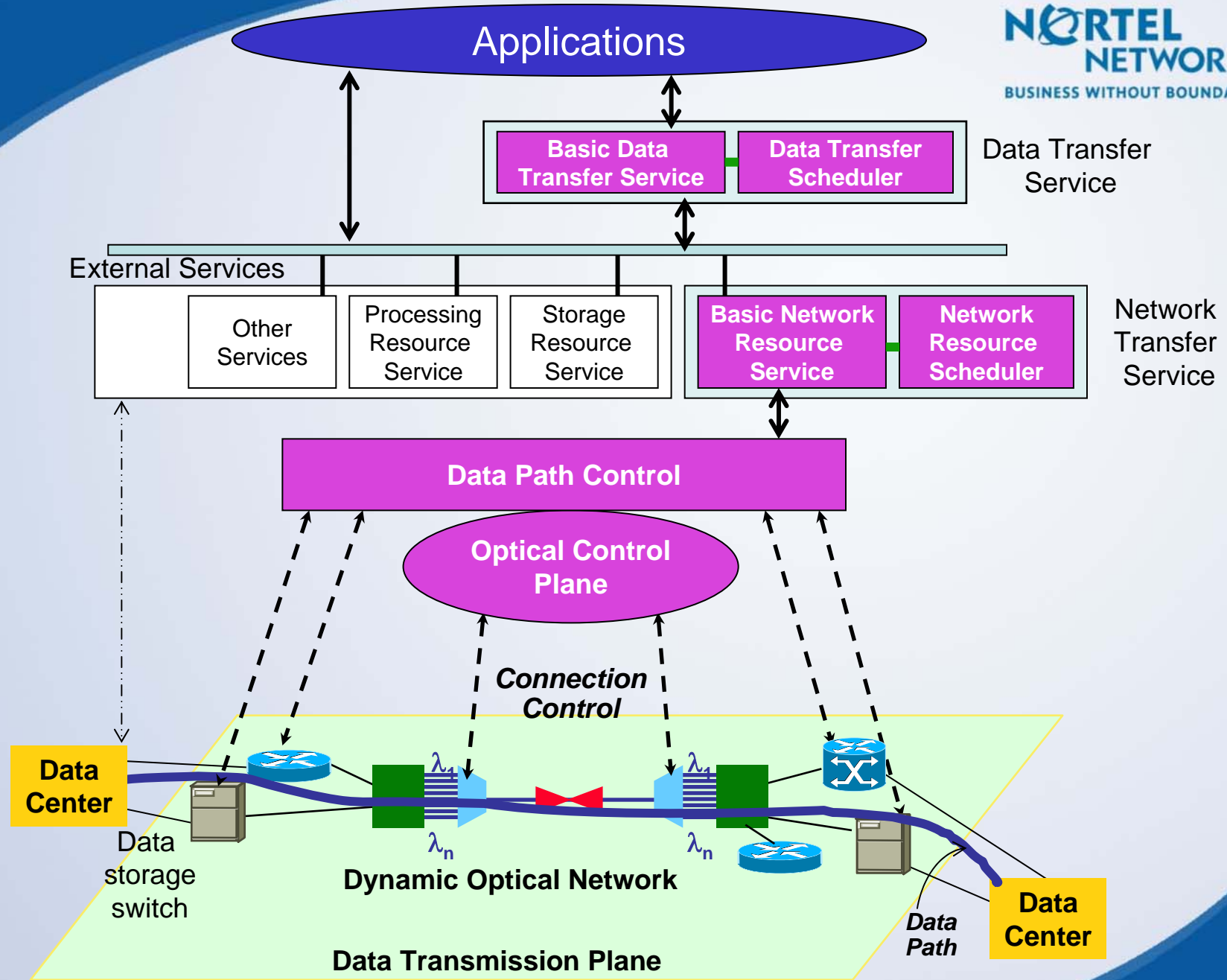
References to experiments using OMNInet

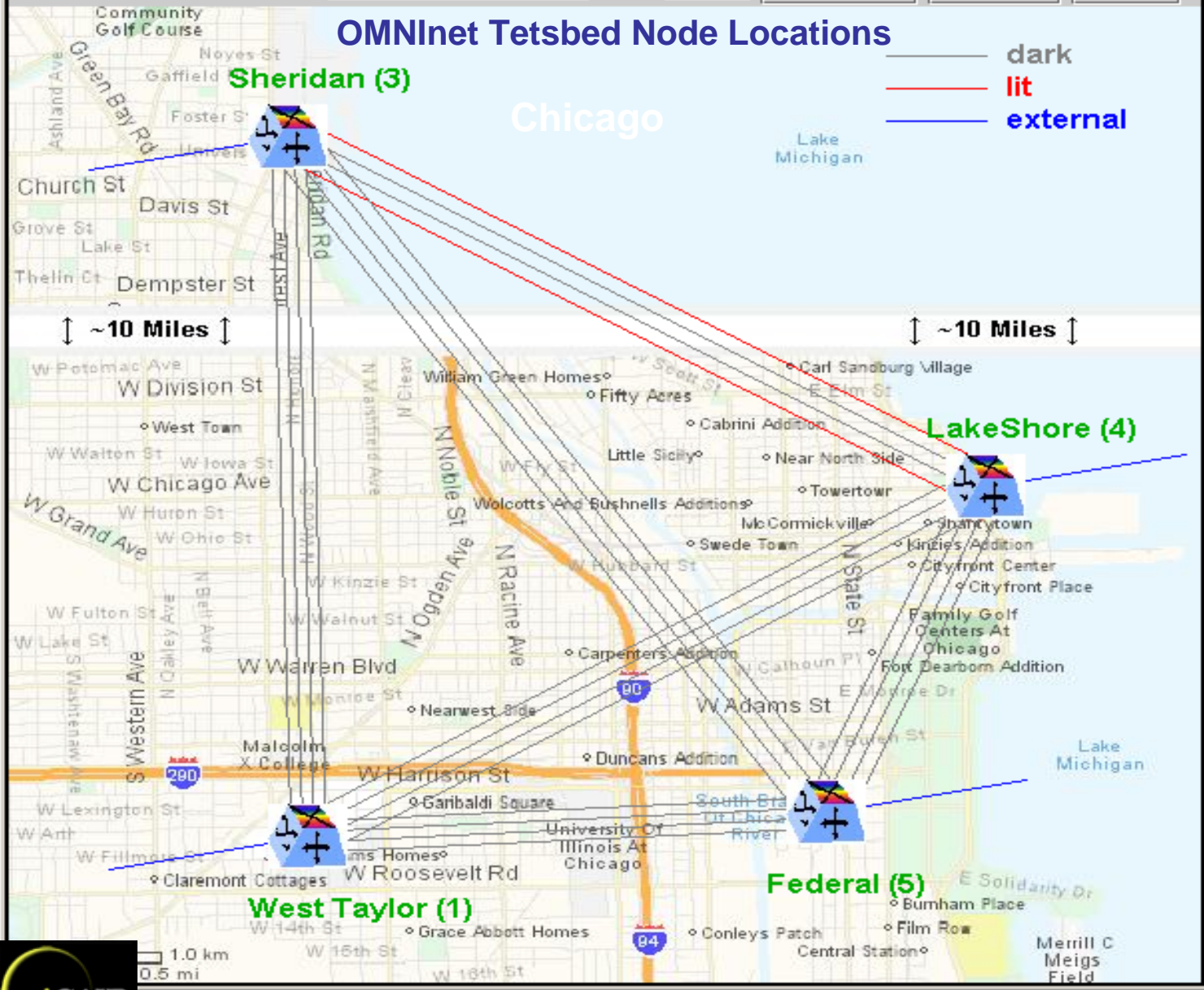
- Photonic TeraStream demonstration over OMNInet
 - <http://www.startap.net/starlight/igrid2002/photonicTeraStream02.html>
- A Case for the Global Access to Large Distributed Data Sets using Data Webs Employing Photonic Data Services
 - http://storageconference.org/2003/papers/08_Grossman-Case.pdf
- Distributed Optical Testbed (OMNInet provides one leg of the DOT)
 - <http://www.dotresearch.org/about.html>
- SABUL experiments over OMNInet
 - <http://www.rgrossman.com/pdf/sabul-hpntp-11-02.pdf>
- Northwestern University Information Technology Annual Report - 2002 (pp14 & 17 refers)
 - <http://www.it.northwestern.edu/AR02/report.pdf>
- FAST TCP Experiments (see last 4-5 charts for OMNInet reference)
 - [FAST v3](#)

DWDM
RAM
Data@LIGHTspeed

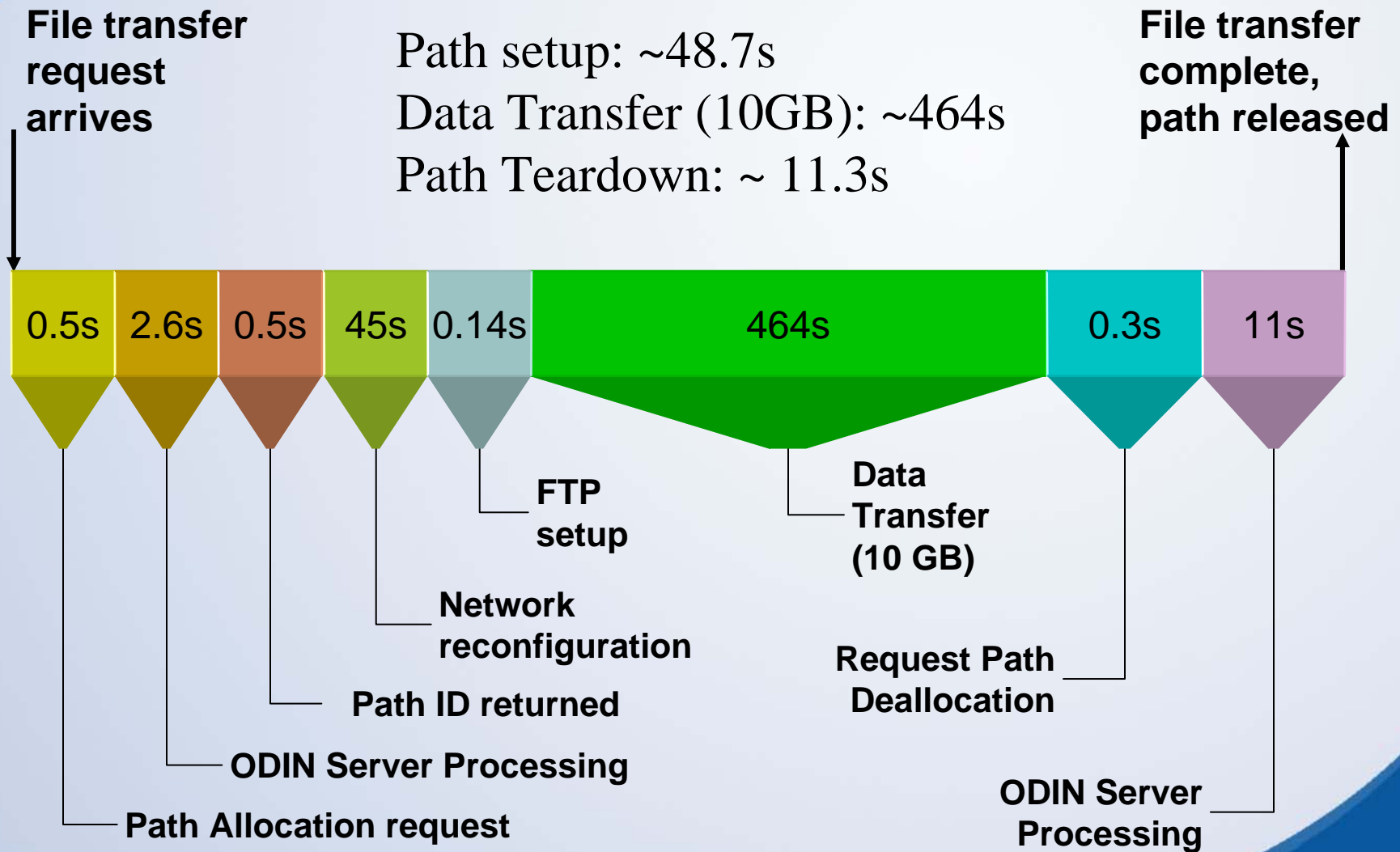
DWDM-RAM

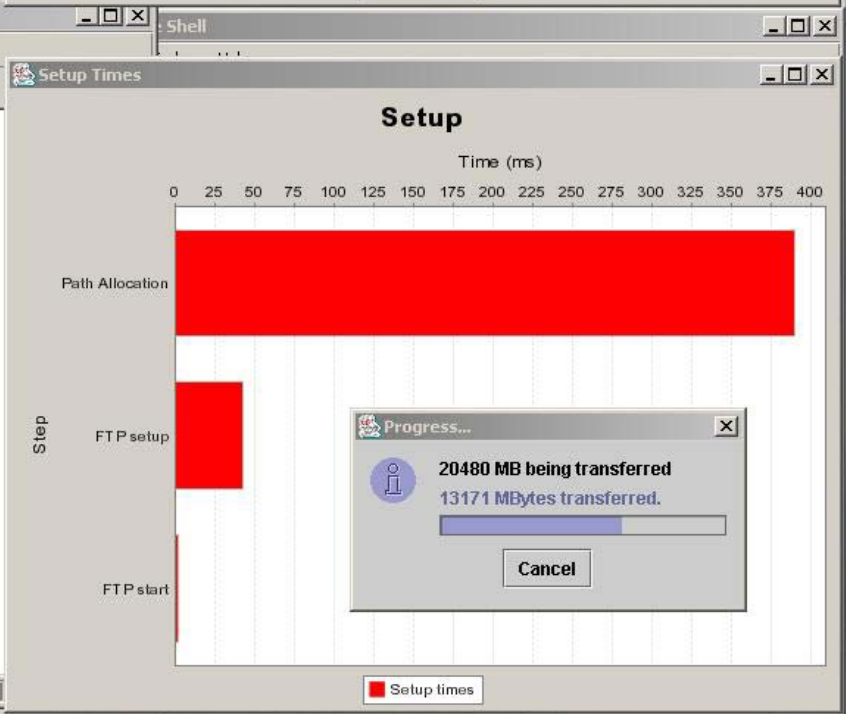
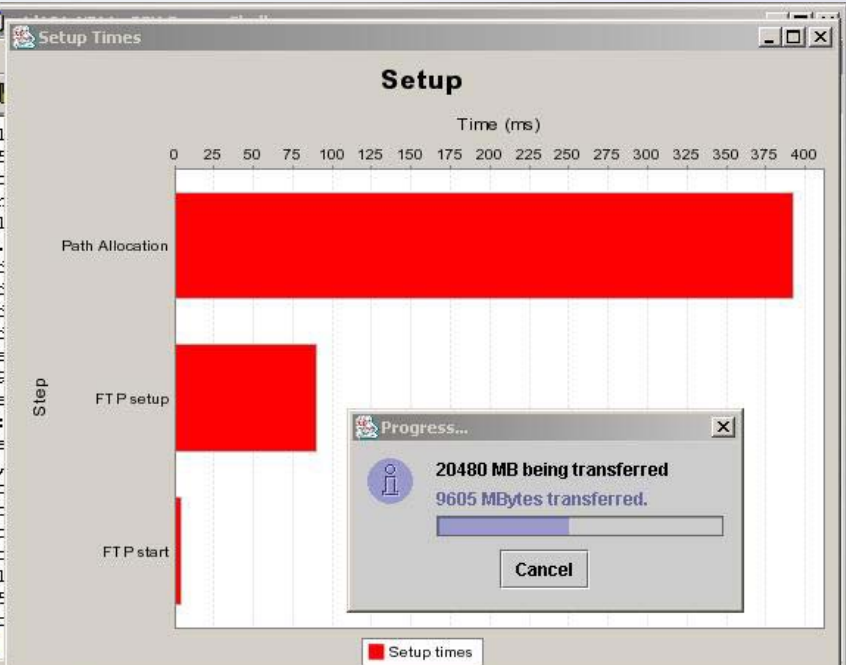
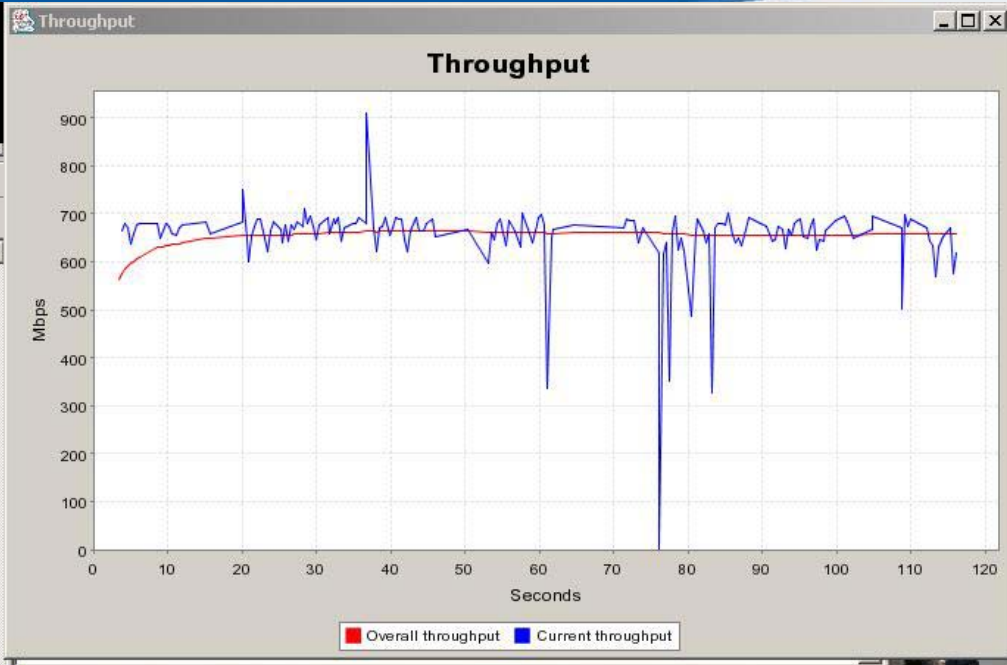
- **DARPA funded research project**
- **Architecture for data-intensive services**
 - **Manage extremely large sets of distributed data**
 - **Dynamic on-demand light path and “e-path” provisioning**
 - **Network resource scheduling**
- **Demonstrations**
 - **GGF9 (Chicago, Oct 2003)**
 - **SC2003 (Phoenix, Nov 2003)**
 - **Chicago, Jun 2004 (SUPERComm)**
- **Current research/experiment activity:**
 - **Multiple sequential service requests**
 - **File transfer performance measurements and metrics**
 - **Other transport protocols**





End-to-end Transfer time (Not Optimized)





DWDM
RAM
Data@LIGHTspeed