Glownet and Bossnet Gigabit Network Infrastructure for e-VLBI

Steven Bernstein, Lorraine Prior, James Calvin, Vineet Mehta

M.I.T. Lincoln Laboratory

e-VLBI Workshop

8-9 April 2002

This work is sponsored by the Defense Advanced Research Projects Agency under Air Force Contract #F19628-00-C-0002. Opinions, interpretations, recommendations and conclusions are those of the authors and are not necessarily endorsed by the Department of Defense.
Glownet and Bossnet Multi-Gigabit/sec Optical Fiber Networks

- **Glownet**
  - Laboratory infrastructure
  - Leased "dark fiber"
  - COTS Gigabit Ethernet and SONET networking
  - Wavelength Division Multiplexed (WDM)

- **Bossnet**
  - DARPA-sponsored testbed
  - Leased "dark fiber"
  - Laboratory-built WDM transmission equipment
  - Experimental

Glownet: Gigabit Lincoln Optical WDM Network

Bossnet (Boston South Optical Network) to Washington D.C.
Outline

• WAN (Bossnet)
• MAN (Glownet)
• LAN
• Processing and Protocols
• Protocols
Bossnet Overview

- ~850 km optically amplified fiber paths
  - fiber leased from Qwest
- Transmission testbed for Gbps++ efforts (WDM, short pulse, new formats, mixed usage)
- Connectivity to NGI (Next Generation Internet) and other projects
- Application demonstration medium for Gbps+ uses
Supernet

http://www.ngi-supernet.org/snet_maps/snet_overview1_raster.htm
Obstacles to Overcome to Increase Data Capacity

- **Noise** - number one issue regardless of transmission format
- **Distortion**
  - Intensity independent
    - polarization mode dispersion (PMD)
    - intersymbol interference (ISI)
  - Intensity dependent
    - self-phase modulation (SPM)
    - cross phase modulation (XPM)
- **Timing jitter**
  - Gordon-Haus effect causes a nonlinear mixing of signal and noise
Bossnet Hut Transmission Hardware

- Each hut has an erbium doped fiber amplifier (EDFA) pair, dispersion compensating fiber (DCF), and amplified spontaneous emission rejection fiber grating (ASE-FG) per direction.

- Some huts have 2x2 switches providing loop-back capability to allow experiments to be performed from a single location.

- OC-3 at 1510 nm is a fully regenerated private channel.
Gain Flattening for BOSSNET

• Measurements made over 570 km
• Erbium fiber amplifier gain profile causes non-uniform signal to noise
• Gain flattening filters installed at most huts
• Negligible change in maximum signal to noise
• Uniform signal to noise over band
• Allows WDM
Outline

• WAN (Bossnet)
• MAN (Glownet)
• LAN
• Processing and Protocols
• Lessons Learned & Summary
'Dark' fiber infrastructure in place with terabit/sec capacity
- Multi-gigabit/sec network equipment deployed

Shared resource with Lincoln, MIT campus, Haystack
- Operational and new applications
  Voice, data, video
  New applications
  radar, VLBI, etc.
- Research
  Networking
  Transmission
  ONRAMP, Bossnet

Low loss, low dispersion fiber

Wavelength Division Multiplexing
Total bandwidth > 1 THz

Operational & New Applications
Commercial: 1 - 40 Gbps per wavelength

Research in Networking & Transmission
Research: > 100 Gbps per wavelength at longer distances
Glownet Dark Fiber

Millstone/ Haystack

Lincoln Laboratory

MIT Campus

230 Congress St. Boston

NeesCom (6)

NStar (2)

NEON (2)

NStar (6)

NeesCom

Bossnet Qwest (4)

(#)= # of fibers

MIT Lincoln Laboratory
GLOWNET Phase I
Networking Equipment

Millstone (RPE Building)
- Cisco 1500 WDM & Transponders
- Transponders
- Wavelength MUX
- 2 GigE (Jumbo Frames)
- OC-48
- 12 10/100 Ethernet
- Growth

Cisco 15454

Lincoln Lab Lexington
- Cisco 1500 WDM & Transponders
- Transponders
- Wavelength MUX
- 2 GigE (Jumbo Frames)
- OC-48
- 12 10/100 Ethernet
- Growth

Boston
- Optical Amplifiers (Ditech)
Outline

• WAN (Bossnet)
• MAN (Glownet)
• LAN
• Processing and Protocols
• Lessons Learned & Summary
Millstone Hill Fiber Infrastructure

- Haystack Radar (HAY)
- Haystack Auxiliary Radar (HAX)
- Millstone Hill Radar (MHR)
- Fiber Infrastructure

To Boston
To Westford
The Whole Path from Haystack to GGAO

Figure 1: e-VLBI Path - Haystack to ISI-E

Figure 2: e-VLBI Path - ISI-E to GSFC/GGAO
Outline

• WAN (Bossnet)
• MAN (Glownet)
• LAN
• Processing and Protocols
• Lessons Learned & Summary
~1 Gbps TCP/IP Demonstration

- TCP/IP data transmitted from Boston to Washington at 990 Mbps between two DEC Alpha workstations

- Transponders convert the optical network interface card output to a transparent channel within Bossnet

- Bit rate-length product was 1.0 Tb-km/s (Initial results summer 2000)

- TCP flow switching:
  - Loopback Boston – New London
MTU & Receiver Window Tuning

![Diagram showing data flow between Host 1, Transponder 1, Delay Path [BOSSNET], Transponder 2, and Host 2.]

**Throughput Performance vs. MTU**

![Graph showing throughput vs. MTU with typical performance indicated.]

**Throughput Performance vs. window size [varying RTT]**

![Graph showing throughput vs. window size with different RTT values.]

- RTT = 0.2 msec
- RTT = 6.2 msec
- RTT = 11.0 msec
- RTT = 15.0 msec

---

MIT Lincoln Laboratory
Onramp Overview

Features:
- WDM Feeder Ring
- Covers 100 - 1000 sq. mi
- 0.1 – 1 Tbps capacity
- Configurable Optics
- Electronic Routing
- IP over WDM
- High speed distribution networks (1-10 Gbps)
- Optical switching
- Dynamic wavelength provisioning
- Flow switching
- Unidirectional or Asymmetric flows
- Protection from link failures

Objective: Aggregation and distribution of data traffic from high rate users, sensors, or LANs to other users, LANs or Backbone Networks
TCP Flow Switch Experiment

Access Node #1 to Access Node #3 to Access Node #2

OADM 1

Control / IP
GbE

Router 1

gbE

Fixed λ Xponder

Tunable λ Xponder

GbE

Splitter

Workstation #1

Control / IP Path
Flow Switched Path

OADM 2

Control / IP
GbE

Router 2

gbE

Fixed λ Xponder

Tunable λ Xponder

GbE

Workstation #2

Delay Path [BOSSNET]

Router 1

OADM 1

OADM 2

Router 2

GbE

Fixed λ Xponder

Tunable λ Xponder

GbE

GbE

GbE
TCP Flow Switching

Flow switch with standard TCP implementation.
- Packets arrive out of order at receiver
- False congestion indication generated
- Congestion avoidance limits sender rate – Degrades Throughput

Flow switch with modified TCP implementation.
- Time stamp option used to recover from false congestion indications
- Throughput degradation avoided
Outline

- WAN (Bossnet)
- MAN (Glownet)
- LAN
- Processing and Protocols
- Lessons Learned & Summary
Lessons Learned (so far)

• Be patient
  – Months are needed to implement a new point-point fiber link with compatible network equipment
  – Numerous "air gaps" must be closed
  – Make sure someone maintains a detailed link and network equipment block diagram (e.g., Alan Whitney)
  – Test links and network equipment early

• Use as much commercial equipment as possible
  – Network equipment is almost standardized
  – But jumbo Ethernet frames are not

• Be prepared to rely on the generosity of others
  – Loaned equipment will work as well as your own and usually arrives sooner

• Be generous sharing your own equipment
  – You will ultimately be rewarded!
Looking Ahead

• How to implement gigabit/sec services "on demand"?
  – Global
  – Metropolitan, e.g., Onramp Program
  – Local
• How to assure compatible networking and transport for all intermediate links?
  – jumbo frames
  – flow switching
• Plan now to get "last kilometer" and "last meter" fiber in place
• Plan now to be sure user equipment can maintain gigabit/sec transfers end-to-end
  – hardware
  – protocols
Summary

• Networking and transport technology is available for global eVLBI
  – but not always where you want it when you want it
• Glownet and Bossnet enable early real-time eVLBI experiments
• Lessons have been learned
Backup
Bossnet Objectives

- Provide an infrastructure for wide area optical link and network research

- Transmission
  - Demonstrate increased capacity through the use of novel waveforms and advanced optical node technology (TDM and WDM)
  - Study propagation effects and mitigation techniques for very high rates over long distances
  - Investigate performance of analog transmission
  - Maintain uninterrupted OC-48 transmission on one wavelength

- Networking
  - Demonstrate wide area all-optical network management and control techniques
  - Interconnect other Gbps testbeds over transparent link
  - Study impact of large Bandwidth-Delay products on transport protocols

- Applications
  - Provide an infrastructure for Gbps research applications
Framingham Hut
Hut Hardware

Laboratory

230 Congress Street, Boston
Desirable Gbps LAN Properties

- Network switches that support jumbo frames
  - Maximum Transmission Unit (MTU) = 9216 bytes
- Network equipment that supports out of band management
  - Remove management traffic from data links
- Network switches with diverse media interfaces
  - GBICs allow SX and LX connections
  - Copper RJ-45 for workstation connections
Glownet Infrastructure

Millstone (RPE Building)
- OC-48 Data Mux
- Wavelength MUX
- Transponders
- 2 GigE (Jumbo frames)
- Growth
- 10/100 Ethernet

Lincoln Laboratory
- Processing Center Computers
- OC-48 Router
- VLAN GigE Switch

Growth
- VLAN GigE Switch LX
- Utility & Display 10/100

Millstone (radar control)
- Millstone (RPE Building)
- HAY
- HAX

Approximately 1 km

Bossnet
- Bossnet Transponder
- WDM
- 230 Congress St., Boston

Westford