e-VLBI Development at Haystack Observatory

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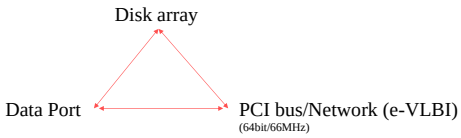
- Phase 1: Develop eVLBI-compatible data system
  - Mark 5 system
- Phase 2: Demonstrate 1 Gbps e-VLBI using Bossnet
  (w/ DARPA and NASA support)
  - ~700km link between Haystack Observatory and NASA/GSFC
  - First e-VLBI experiment achieved ~788Mbps transfer rate
- Phase 3: Develop adaptive network protocol
  (newly awarded NSF grant to Haystack Observatory; collaboration with MIT Lab for Computer Science and MIT Lincoln Laboratory);
  - New IP-based protocol tailored to operate in shared-network 'background' to efficiently using available bandwidth
  - Demonstrate on national and international networks
- Phase 4: Extend e-VLBI to national and global VLBI community
  - 'Last mile' problem remains a serious challenge

Mark 5 e-VLBI Connectivity

- Mark 5 supports a triangle of connectivity for e-VLBI requirements



Mark 5 can support several possible e-VLBI modes:
- e-VLBI data buffer (first to Disc Array, then to Network); vice versa
- Direct e-VLBI (Data Port directly to Network); vice versa
- Dual Gigabit Ethernet connections will be necessary to support for 1024 Mbps; new motherboards are being examined

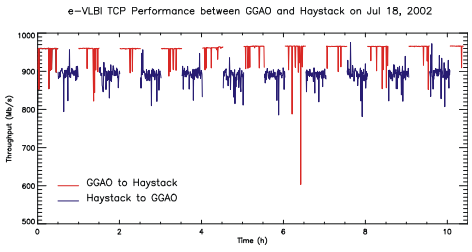
More information at www.haystack.edu

e-VLBI

- 1 Gbps e-VLBI demonstration experiment between Westford and GGAO; data transfer to Haystack correlator in near-real-time (www.haystack.edu/e-vlbi)
- Several Westford/Kashima e-VLBI experiments
- Establishing e-VLBI connections to Kokee Park and U. of Regensburg (near Wettzell) for near-real-time Intensive UT1 demonstrations
- e-VLBI is very high visibility in networking community
- Much is going on
  - Haystack has 3-yr grant from NSF for development of new protocols for e-VLBI
  - Haystack is co-PI on two major proposals in U.S.

Bossnet 1 Gbps e-VLBI demonstration experiment

Performance test results – Haystack/GGAO



Average sustained rate >900 Mbps over 10 hours

Westford-GGAO e-VLBI results

First near-real-time e-VLBI experiment conducted on 6 Oct 02
- Recorded data at 1152 Mbps on Westford-GGAO baseline
- GGAO disk-to-disk transfer at average 788 Mbps transfer rate
- Immediate correlation on Haystack Mark 4 correlator
- Nominal fringes observed

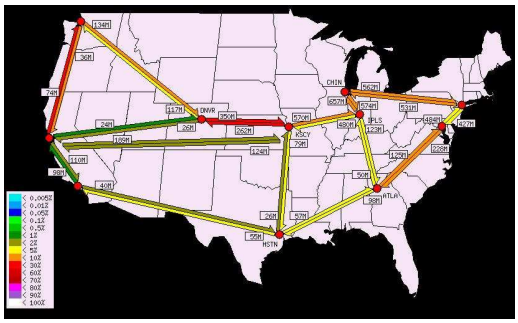
- Direct data transfer experiment conducted on 24 Oct 02
  - Direct transfer of GGAO data to disk at Haystack at 256 Mbps
  - Immediate correlation with Westford data
  - Nominal fringes observed
- Next step – full real-time e-VLBI
  - Mark 5 system is capable of transmitting in real-time
  - But, still need additional work on correlator software to synchronize correlator operation to real-time
- Conclusion
  - e-VLBI at near Gbps speeds over ordinary shared networks is possible but still difficult
- Full report at

`ftp://web.haystack.edu/pub/e-vlbi/demo_report.pdf`

International e-VLBI experiments

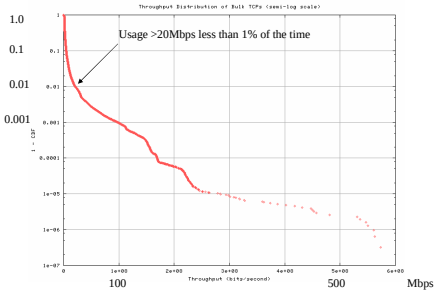
- Westford, MA to Kashima, Japan - experiments in Oct 02 and Mar 03
  - Record Mark 5 at Westford - K5 at Kashima
  - Files exchanged over Abilene/GEMnet networks
    - Nominal speed expected to be ~20 Mbps; best achieved so far ~11 Mbps
  - Software format transformation
  - Correlation on Mark 4 correlator at Haystack and PC Software correlator at Kashima
  - Normal fringes obtained
  - Further experiments are scheduled; network tuning is in progress
- Kauai, Hawaii and Wettzell, Germany (in progress)
  - Daily experiments of ~100GB are ideal candidate for early e-VLBI
  - Data will be transferred to Haystack Observatory for processing (OC-3 speeds are possible)
  - Network links are now being brought up

Abiline Network Backbone – 25 June 2003



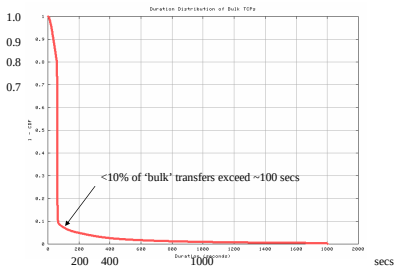
Line Utilization

Typical bit-rate statistics on Abilene network



Conclusion: Average network usage is only a few % of capacity

Typical distribution of heavy traffic on Abilene



Conclusion: Heavy usage of network tends to occur in bursts of <2 minutes

New IP Protocols for e-VLBI

- Based on observed usage statistics of networks such as Abilene, it is clear there is much unused capacity
- New protocols are being developed to utilize networks in 'background' mode for applications such as e-VLBI
  - Take advantage of special characteristics of e-VLBI data
  - Will 'scavenge' and use 'secondary' bandwidth
  - Will give priority to 'normal' users
  - Requires a new 'end-point adaptive strategy'
- Work being carried out by MIT Haystack Observatory in collaboration with MIT Laboratory for Computer Science and MIT Lincoln Laboratory
  - 3-year program; will demonstrate e-VLBI connections both nationally and internationally
  - Dr. David Lapsley has joined Haystack staff to lead this effort

But there is a significant problem – 'Last-mile' costs

- Most of the world's telescopes are not well connected
- Electronic and electro-optic costs are dropping rapidly
  - GigE switch: 2001 - $15K 2003 - $1.2K
  - GigE transceivers 2001 - $750 2003 - $180
  - CWDM transceivers $400-800 for 50-100km reach!
- Direct fiber cost is relatively low– $60/fiber-km in 80-fiber bundle
- If you can buy or lease existing fiber, there is no better time!
- But – fiber installation cost is still tall pole
  - Europe: >$20/m (or any populous wide-area)
  - U.S.: >$10/m (in simplest desert environment)
- The upside: there is developing a lot of momentum and support from the greater networking community to get the job done!

Also desperately needed:
- Modern digital filter banks to replace aging and obsolete analog BBC's!

….and a longer term e-VLBI issue as well

- Can e-VLBI survive the long-term networking costs?

…and some hope!

- There is momentum gathering in the networking community to provide national and international ultra-high-speed networking as a critical 'enabling infrastructure' for U.S. and international science. The NSF 'Atkin's Report' recommends spending $1B/yr for the next 5 years to improve the U.S. 'cyberinfrastructure'.
- The astronomy community needs to makes its voice heard loud and clear!

Conclusions

- e-VLBI is riding an unprecedented wave of global network connectivity and networking community enthusiasm.
- There is no better time to lease or buy installed fiber than now!
- Gradual transition from disks to disk/e-VLBI to all e-VLBI is likely.
- 10-100 Gbps/antenna is technically possible with e-VLBI. (Can VLBI correlators keep up?!)
- Haystack is moving aggressively to exploit these new technologies

Details of path from Haystack to GGAO: Part 1

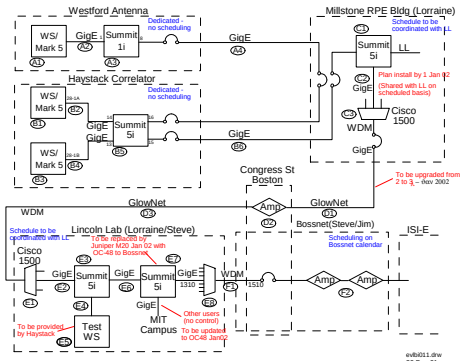


Figure 1: e-VLBI Path - Haystack to ISI-E

Details of path from Haystack to GGAO: Part 2

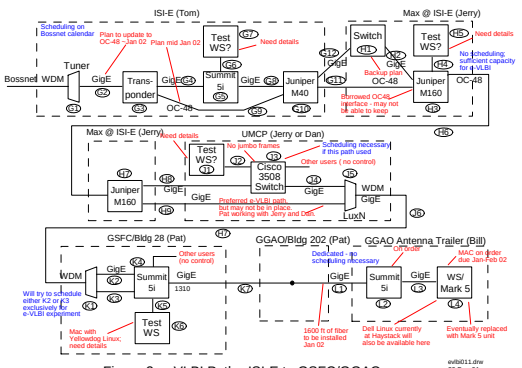
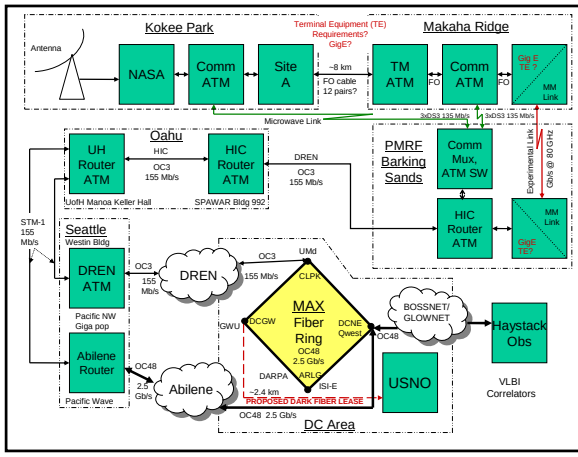


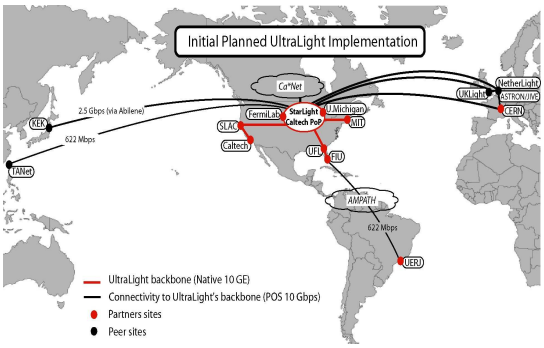
Figure 2: e-VLBI Path - ISI-E to GSFC/GGAO



UltraLight

(An Ultra-scale Optical Network Laboratory for Next Generation Science)

- Packet-switched and circuit-switched hybrid experiment research network with transcontinental 10Gbps wavelengths on National Light Rail
- Collaboration of Caltech, MIT Haystack, U. of Florida, Florida IU, U. Mich, SLAC, Fermilab, CERN and others; commercial partner Cisco Systems
- Partner projects TransLight, Netherlight, ULlight, AMPATH, CA*Net4
- Flagship applications
  - High-energy physics
  - e-VLBI
  - High-resolution near-real-time medical imaging
- New techniques to be explored
  - End-to-end monitoring agents to determine how to best manage network data flows
  - Dynamic traffic routing
  - Dynamic scheduling of additional wavelengths
  - 'Tunneling' protocols to set up sub-paths with guaranteed BW
- Key part of proposal is to develop plan for connecting U.S. antennas
- Proposed 5-year project, ~$10M, with several M$ contribution from industry



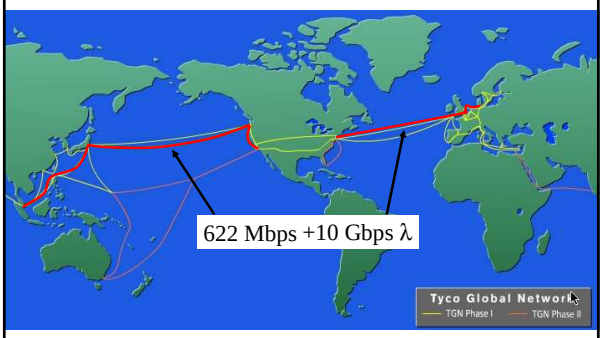
DRAGON

(Dynamic Resource Allocation via GMPLS Optical Networks)

- Collaboration with Univ. of Maryland, Mid-Atlantic Crossroads (MAX), Information Sciences Institute (USC) and NASA/GSFC
- Develop a Generalized MultiProtocol Label Switching (GMPLS) network to provide deterministic network resources at the packet, wavelength, and fiber cross-connect levels
- Will develop a set of API's for application-level use of GMPLS
- Industry partner Movaz Networks will provide pre-production GMPLS-enabled wavelength-selective switches (MEM's based switching fabric)
- Proposed 4-year project

VSI-E

- VSI-H defines input and output interfaces of a VLBI data system, but specifically excludes details of media or data format
- However, e-VLBI intercompatibility among heterogeneous VLBI data systems is highly desirable
- Consequently, the VSI technical development committee is now turning its attention to this problem
- Goal is define a common e-VLBI data protocol and format, called 'VSI-E'
- First rough draft has been created and distributed to form a basis for further discussion
- It now appears that some variation of RTP protocol may be most suitable for VSI-E
- Goal: Complete VSI-E specification by end 2003!



Transoceanic donations to IEEAF (in red)

AMPATH: Research and Education Network and International Exchange Point for the Americas

- Launched in March 2000 as a project led by Florida International University (FIU), with industry support from Global Crossing (GX), Cisco Systems, Lucent Technologies, Juniper Networks and Terremark Worldwide
- Enables wide-bandwidth digital communications between the Abilene network and 10 National Research and Education Networks (NRNs) in South and Central America, the Caribbean and Mexico
- Provides connectivity to US research programs in the region
- AMPATH is a project of FIU and the National Science Foundation's Advanced Networking Infrastructure & Research (ANIR) Division

Note: VLBI telescopes currently in Chile and Brazil