e-VLBI Development at Haystack Observatory

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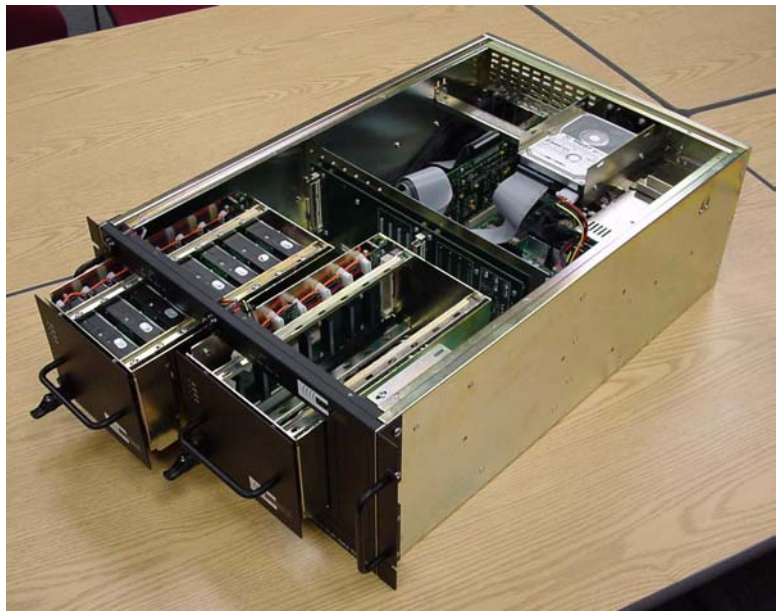
e-VLBI program overview

- Mark 5 VLBI data system
- 1 Gbps demonstration e-VLBI experiment
- National and international e-VLBI experiments
- Development of special e-VLBI protocols
- New UltraLight project (proposed)
- New DRAGON project (proposed)
- VSI-E development

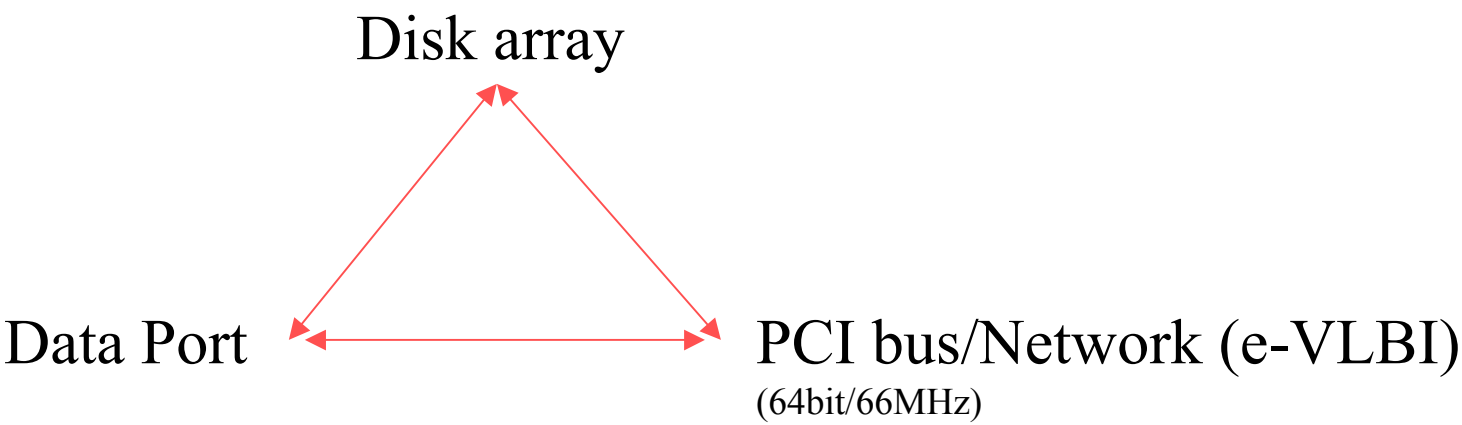
Mark 5A VLBI Disk-Based Data System



- 1 Gbps continuous recording/playback to/from set of 8 inexpensive (ATA) disks
- Based primarily on COTS components
- Two removable '8-pack' disk modules in single 5U chassis
- With currently available 200GB disks – capacity of single '8-pack' 1.6TB; expected to increase to 2.5TB by late 2003 with 320GB disks
- Network connection for real-time and quasi-real-time e-VLBI operations
- Inexpensive: ~$16K fully assembled and tested
- ~30 Mark 5 systems now installed at stations and correlators; expect ~50 by end 2003
- VSI-compatible version (Mark 5B) to ready early 2004

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/mark5

Bossnet 1 Gbps e-VLBI demonstration experiment

Westford

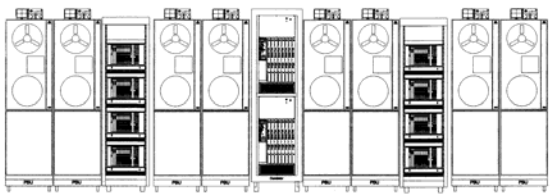
Haystack
(correlator)

Future

Initial experiment

USNO
(correlator)

NASA/GSFC



Details of path from Haystack to GGAO: Part 1

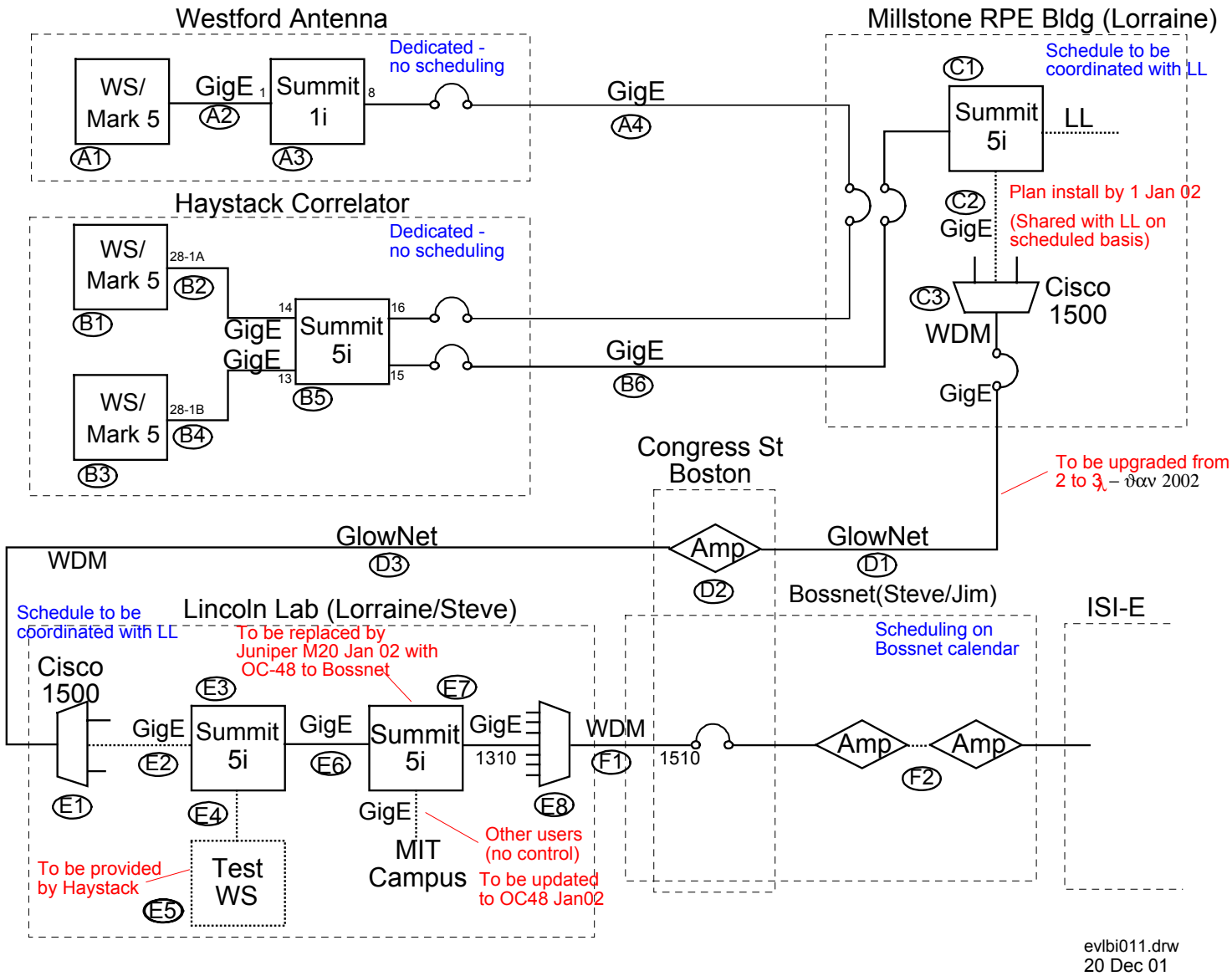


Figure 1: e-VLBI Path - Haystack to ISI-E

Details of path from Haystack to GGAO: Part 2

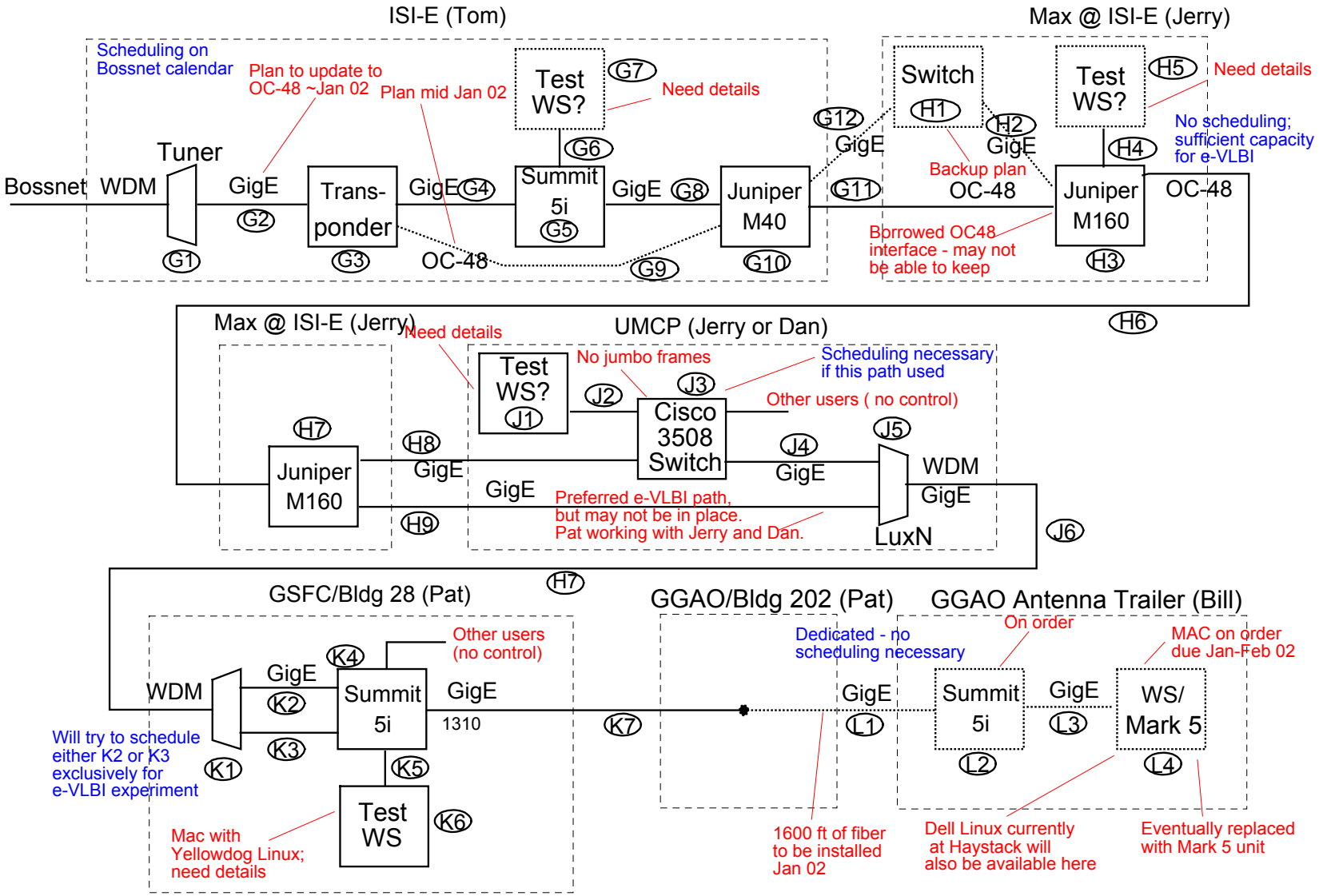
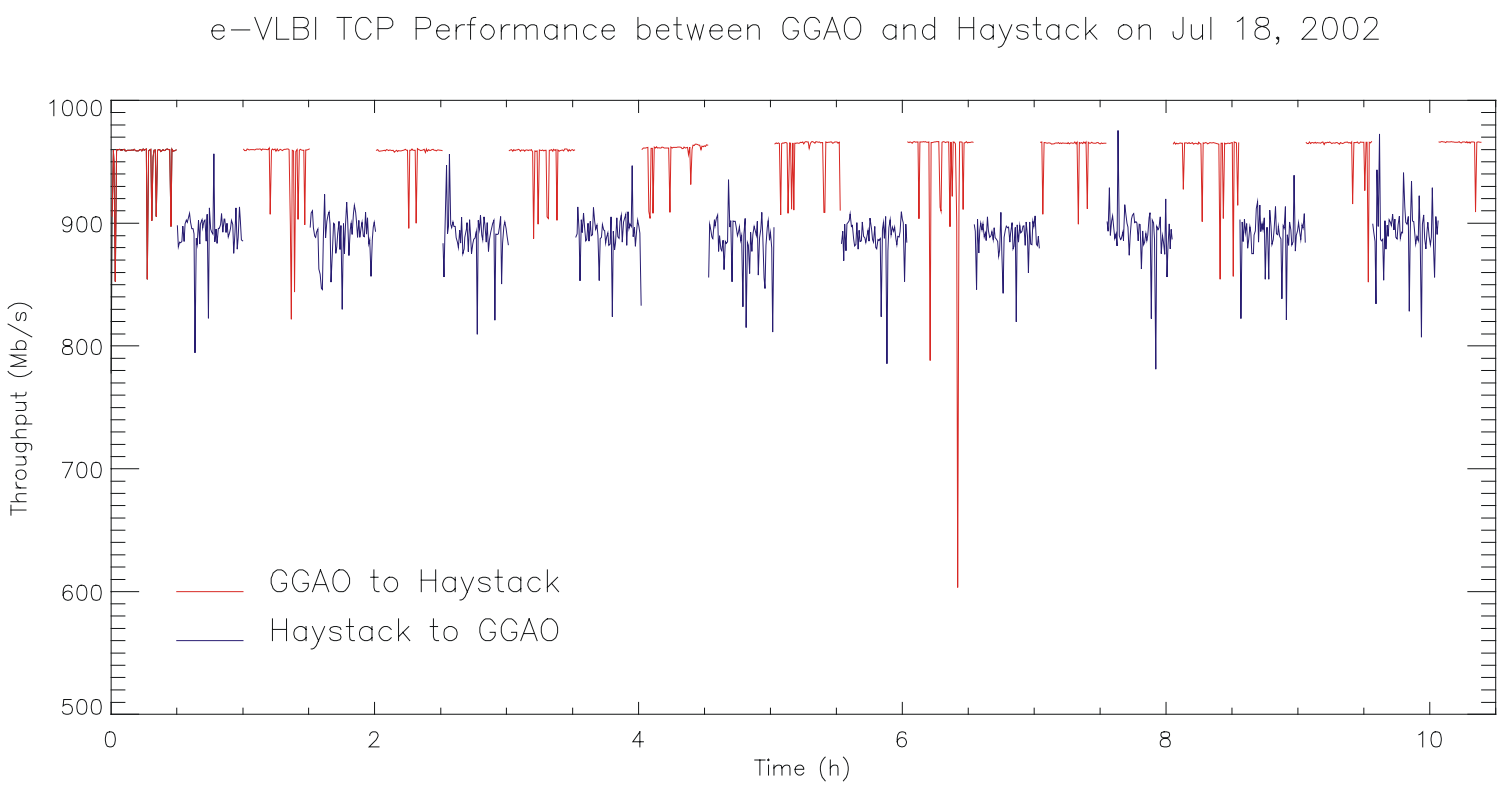


Figure 2: e-VLBI Path - ISI-E to GSFC/GGAO

evlbi011.drw
20 Dec 01

Performance test results – Haystack/GGAO



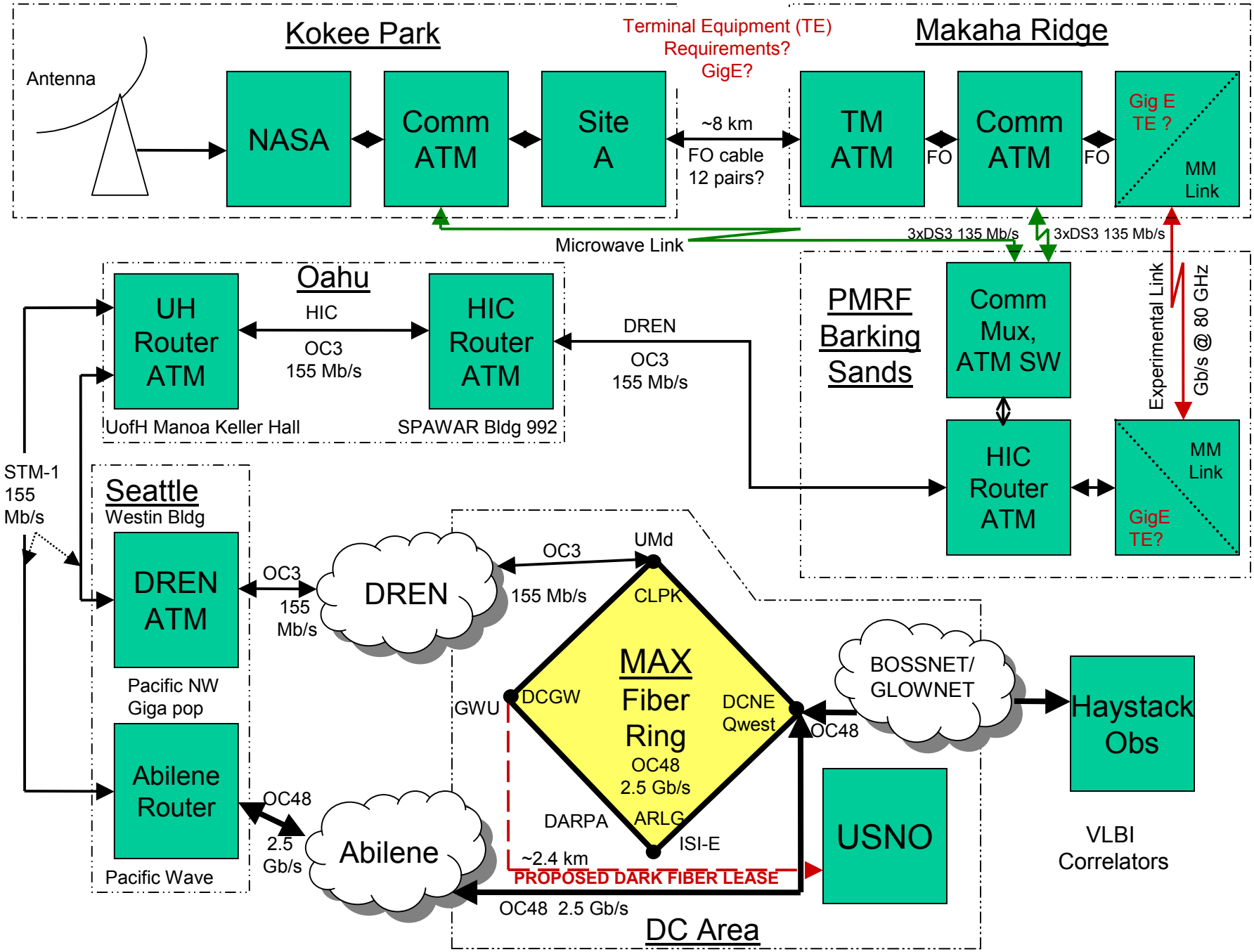
Average sustained rate >900 Mbps over 10 hours

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
  - Hope to conduct first experiment in early 2003
- Conclusion
  - e-VLBI at near Gbps speeds over ordinary shared networks is possible but still difficult
- Full report at www.haystack.edu/e-vlbi

International e-VLBI experiments

- Westford, MA to Kashima, Japan - experiments in Oct 02 and Mar 03
  - Files exchanged over Abilene/GEMnet networks
    - Nominal speed expected to be ~20 Mbps; best achieved so far ~11 Mbps
  - Correlation on Mark 4 correlator at Haystack and PC Software correlator at Kashima; nominal fringes obtained
  - Further experiments are scheduled; network tuning is in progress
- Kauai, Hawaii to 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


Kokee Park
Terminal Equipment (TE) Requirements? GigE?
Makaha Ridge
Antenna
NASA
Comm ATM
Site A
~8 km
FO cable 12 pairs?
TM ATM
FO
Comm ATM
FO
Gig E TE ?
MM Link
Microwave Link
3xDS3 135 Mb/s
3xDS3 135 Mb/s
Oahu
UH Router ATM
HIC
OC3 155 Mb/s
HIC Router ATM
DREN
OC3 155 Mb/s
PMRF Barking Sands
Comm Mux, ATM SW
Experimental Link
Gb/s @ 80 GHz
UofH Manoa Keller Hall
SPAWAR Bldg 992
HIC Router ATM
MM Link
GigE TE?
STM-1 155 Mb/s
Seattle
Westin Bldg
DREN ATM
OC3 155 Mb/s
DREN
OC3
155 Mb/s
UMd
CLPK
MAX Fiber Ring
OC48
2.5 Gb/s
GWU
DCGW
DCNE
Qwest
OC48
BOSSNET/ GLOWNET
Haystack Obs
Pacific NW Giga pop
Abilene Router
OC48
2.5 Gb/s
Abilene
DARPA
ARLG
ISI-E
~2.4 km
PROPOSED DARK FIBER LEASE
USNO
VLBI Correlators
Pacific Wave
OC48 2.5 Gb/s
DC Area

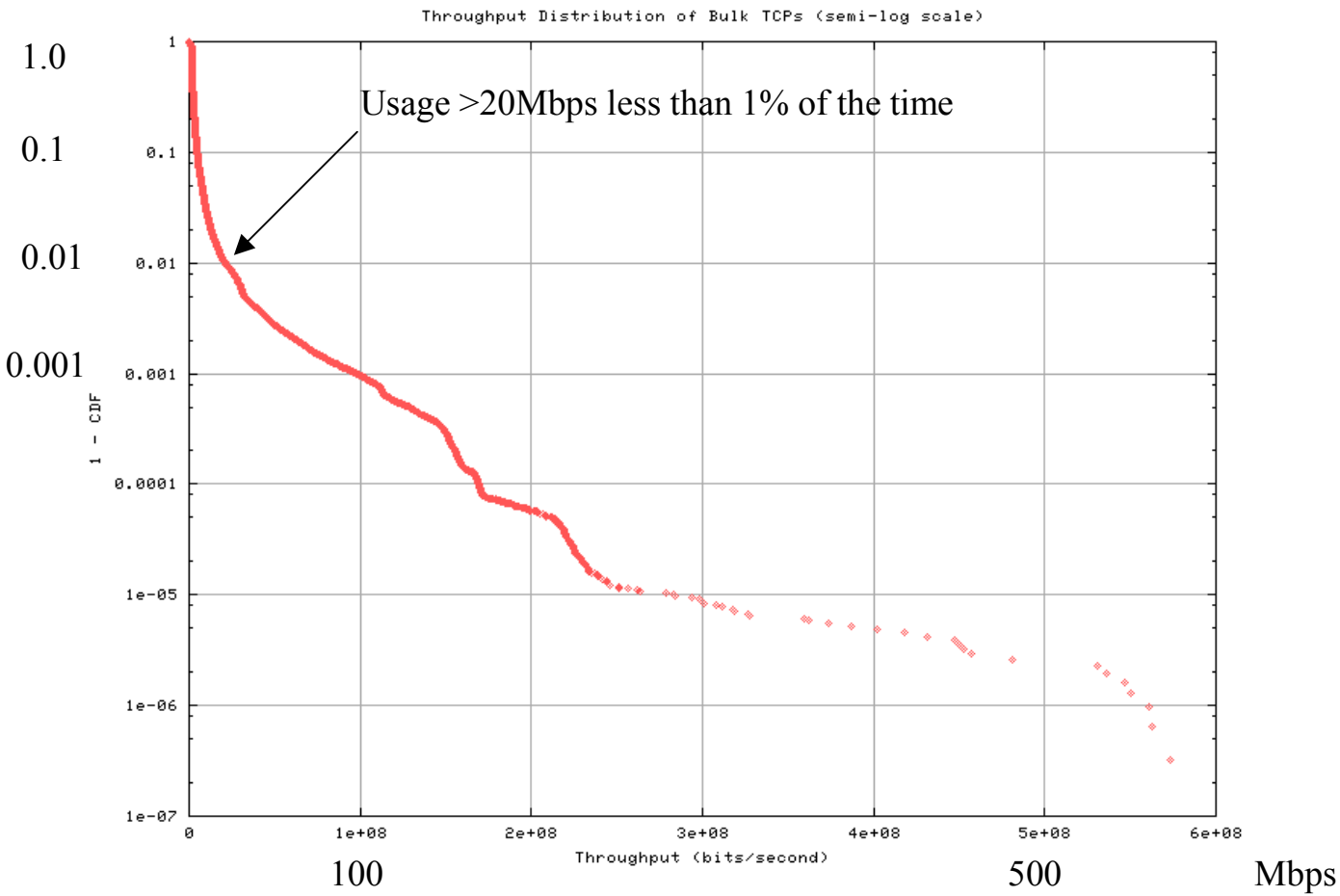
Further extensions to national and global community

- Possibilities for international connections
  - Surfnet – U.S. to Europe at 2.5 Gbps
  - TransPAC – U.S. to Japan at 655 Mbps (upgrade to 1.2 Gbps planned)
  - GEMnet – currently ~20 Mbps, planning to upgrade to 2.2 Gbps
  - APAN – U.S. to Japan at 655 Mbps
  - AMPATH – possible connections to telescopes in Chile and Brazil
  - A sample of others under construction
    - TEIN – Paris to Seoul
    - EUMEDCONNECT – Europe to Mediterranean
    - NeDAP – Europe to Russia
    - ALIS – Europe to Latin and South America
  - One of the most interesting!
    - IEEAF –Europe/U.S. link at 10 Gbps!
    - Donated by Tyco, Inc.
  - Dedicated-lambda networks are being investigated as possibility

New IP Protocols for e-VLBI

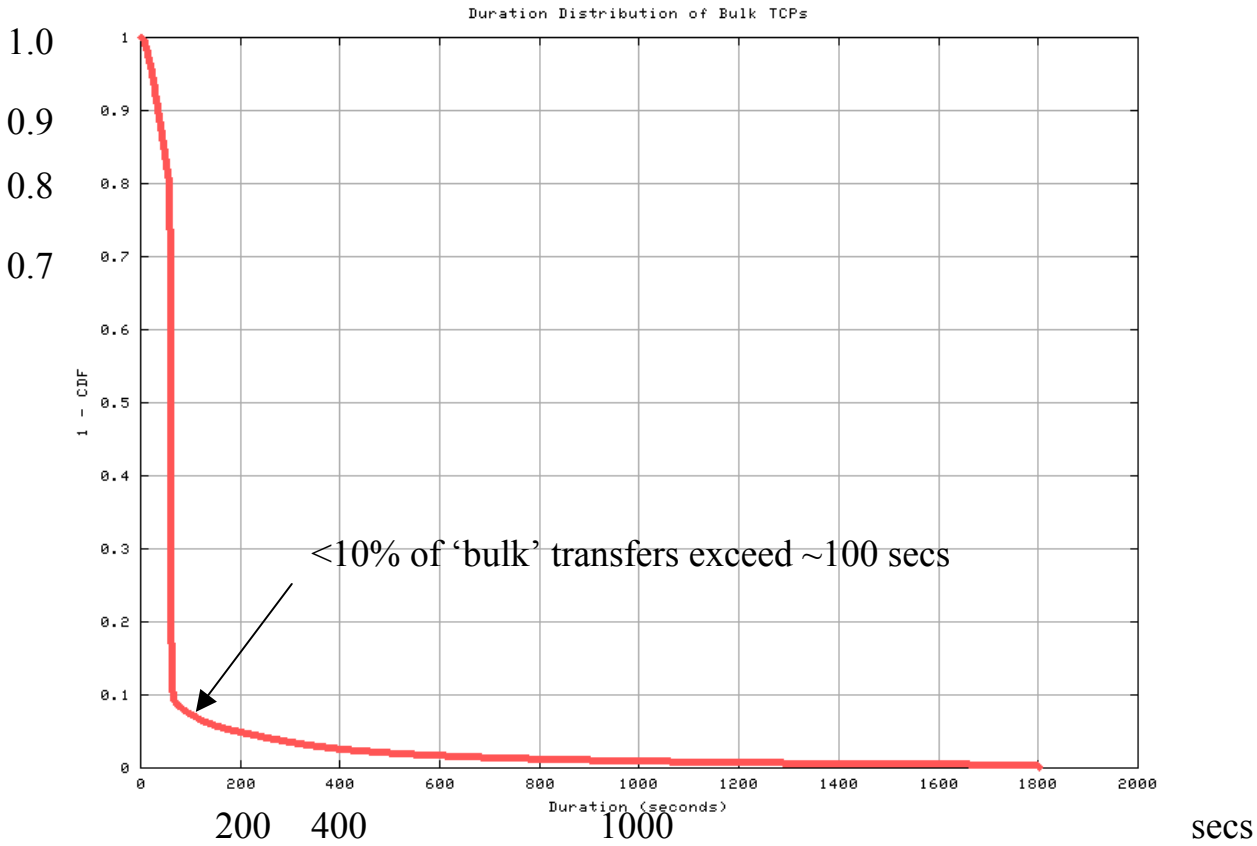
- Based on observed usage statistics of networks such as Abilene, it is clear there is much unused capacity
- New protocols are being developed to utilize networks in 'background' mode for applications such as e-VLBI
  - Take advantage of special characteristics of e-VLBI data
  - Will 'scavenge' and 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
  - Funded 3-year program; will demonstrate e-VLBI connections both nationally and internationally
  - Dr. David Lapsley has joined Haystack staff to lead this effort

Typical bit-rate statistics on Abilene network



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

Typical distribution of heavy traffic on Abilene

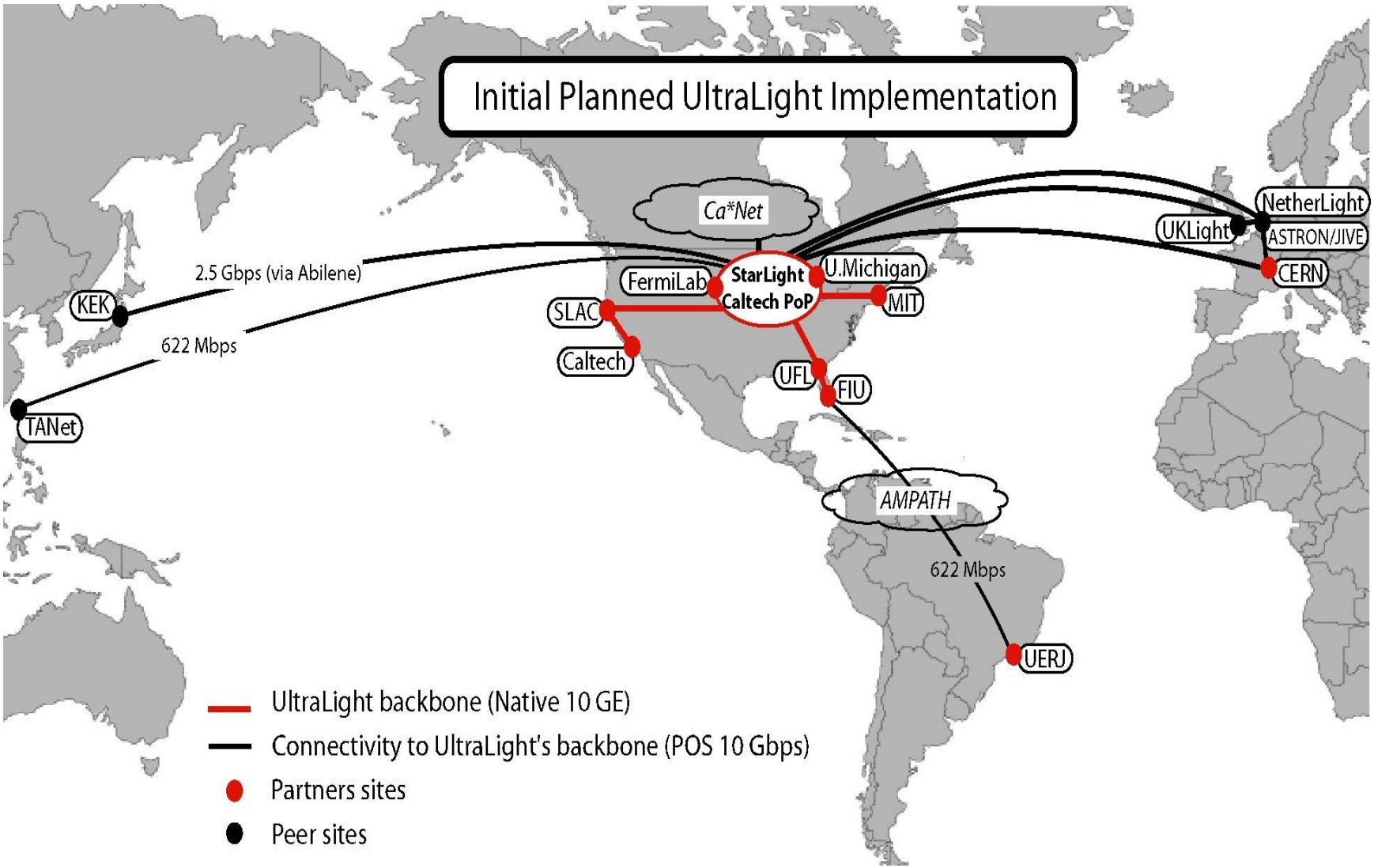


Conclusion: Heavy usage of network tends to occur in bursts of <2 minutes

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


Initial Planned UltraLight Implementation
Ca*Net
NetherLight
UKLight
ASTRON/JIVE
CERN
2.5 Gbps (via Abilene)
KEK
622 Mbps
TANet
FermiLab
StarLight
Caltech PoP
U.Michigan
MIT
SLAC
Caltech
UFL
FIU
AMPATH
622 Mbps
UERJ
UltraLight backbone (Native 10 GE)
Connectivity to UltraLight's backbone (POS 10 Gbps)
Partners sites
Peer sites

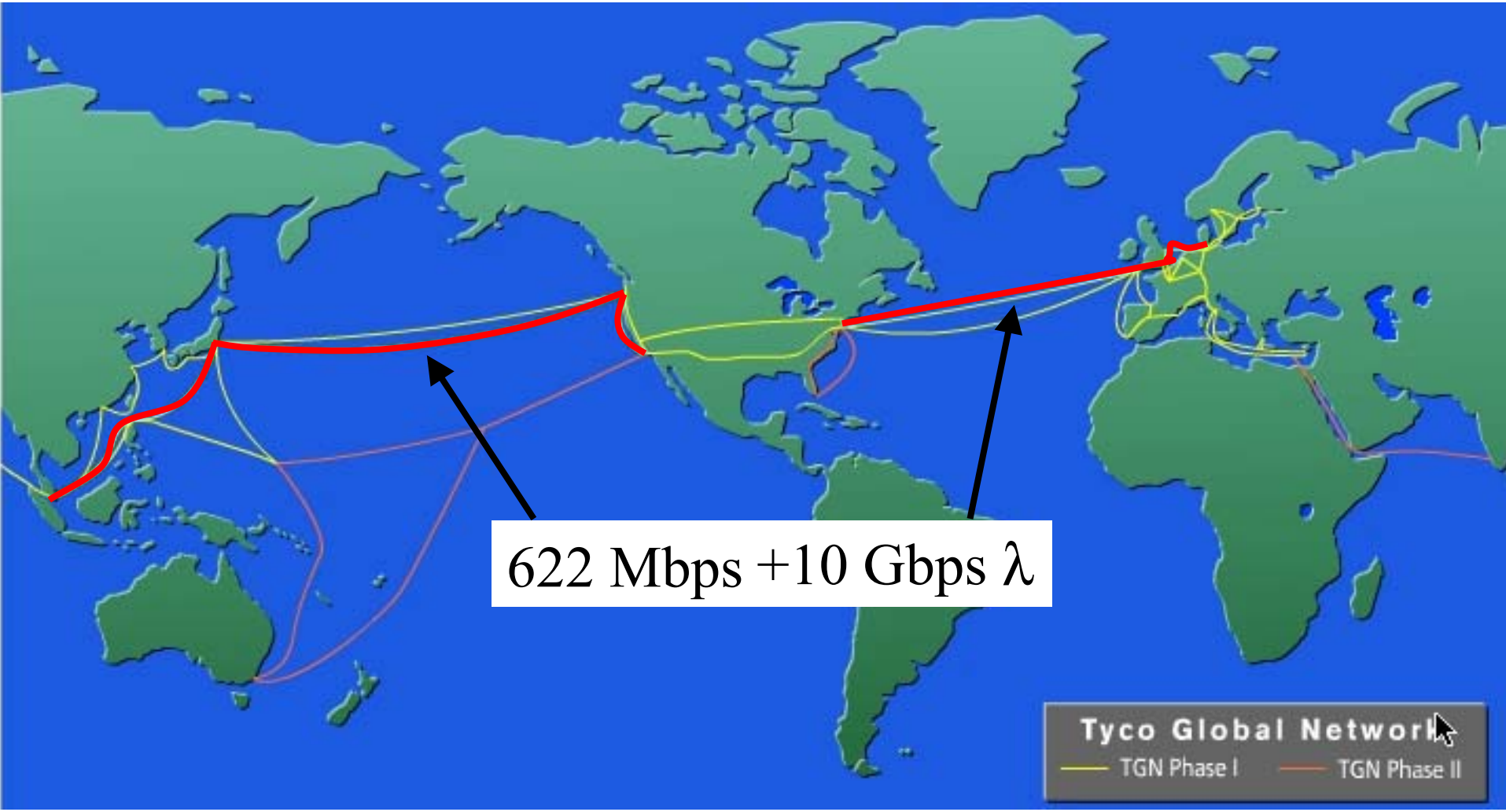
DRAGON

(Dynamic Resource Allocation via GMPLS Optical Networks)

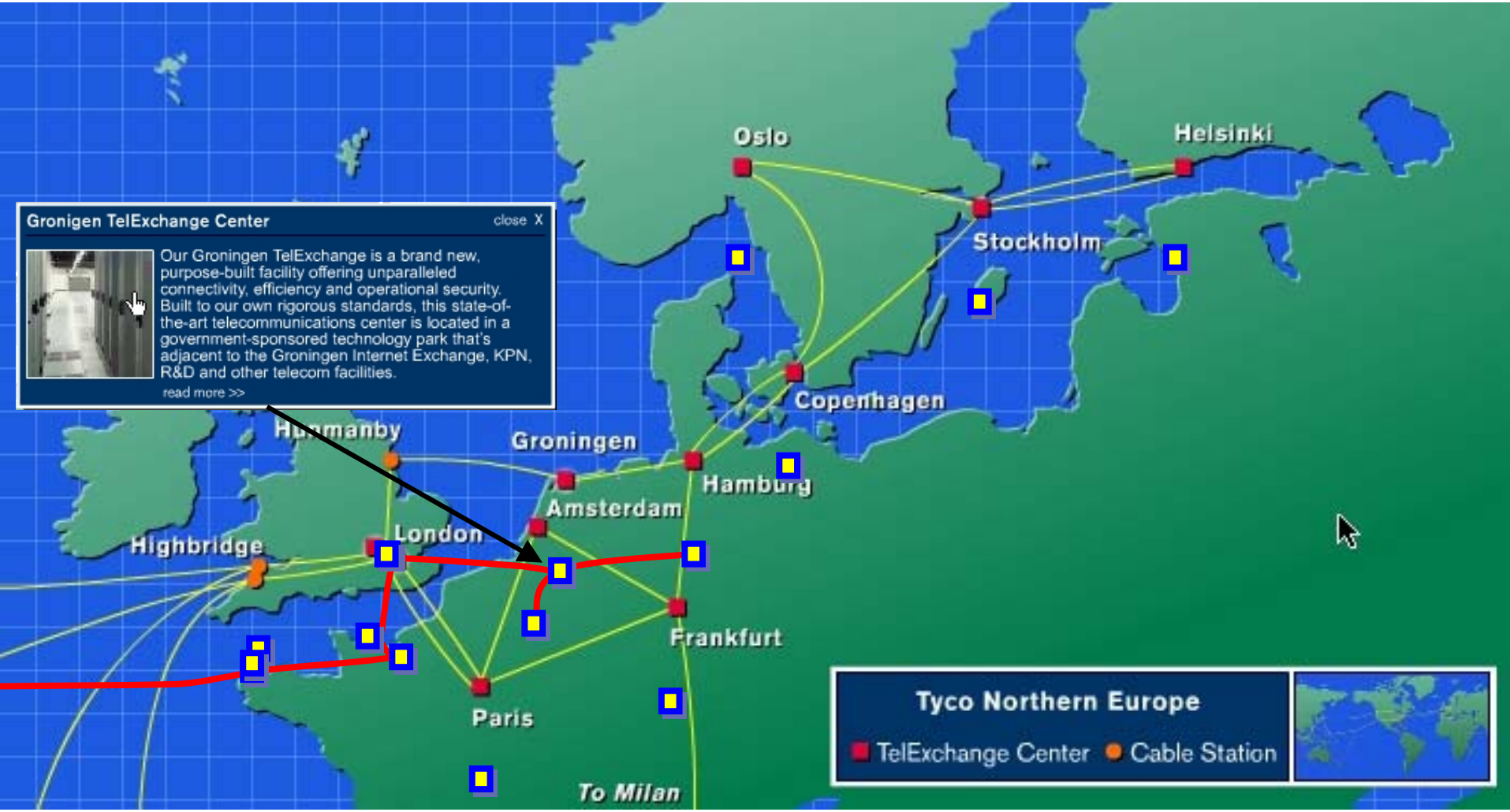
- Collaboration with Univ. of Maryland, Mid-Atlantic Crossroads (MAX), Information Sciences Institute (USC) and NASA/GSFC
- Develop a Generalized MultiProtocol Label Switching (GMPLS) network to provide deterministic network resources at the packet, wavelength, and fiber cross-connect levels
- Will develop 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
- A rough draft RTP protocol for e-VLBI will be presented by David Lapsley; we hope to have further discussion at this meeting
- Goal: Complete VSI-E specification by end 2003!



Transoceanic donations to IEEAF (in red)



Northern Europe 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