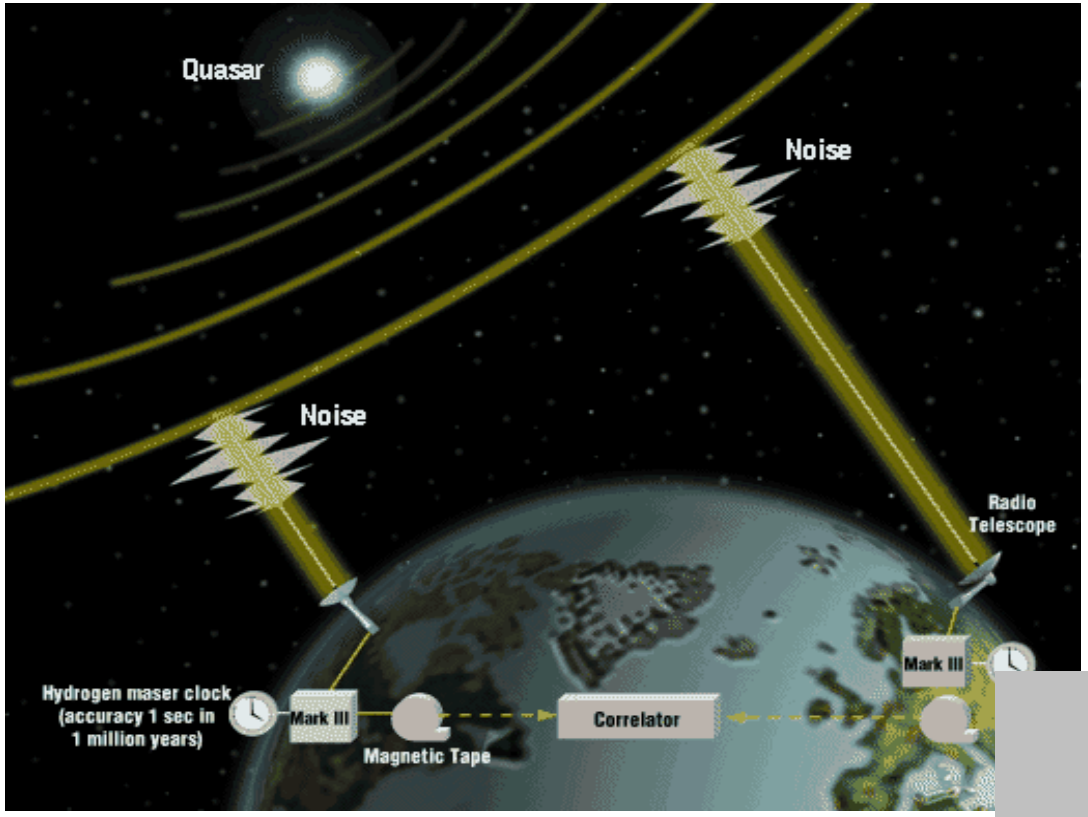
e-VLBI: A Brief Overview

Alan R. Whitney
MIT Haystack Observatory

The Very-Long Baseline Interferometry (VLBI) Technique

(with traditional data recording)



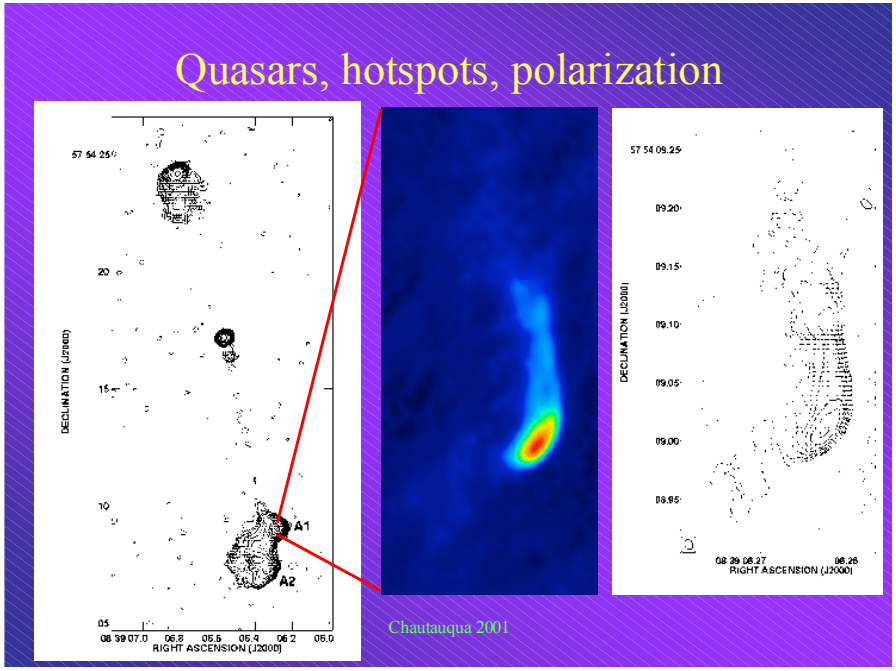
The Global VLBI Array

(up to ~20 stations can be used simultaneously)

VLBI Science

ASTRONOMY

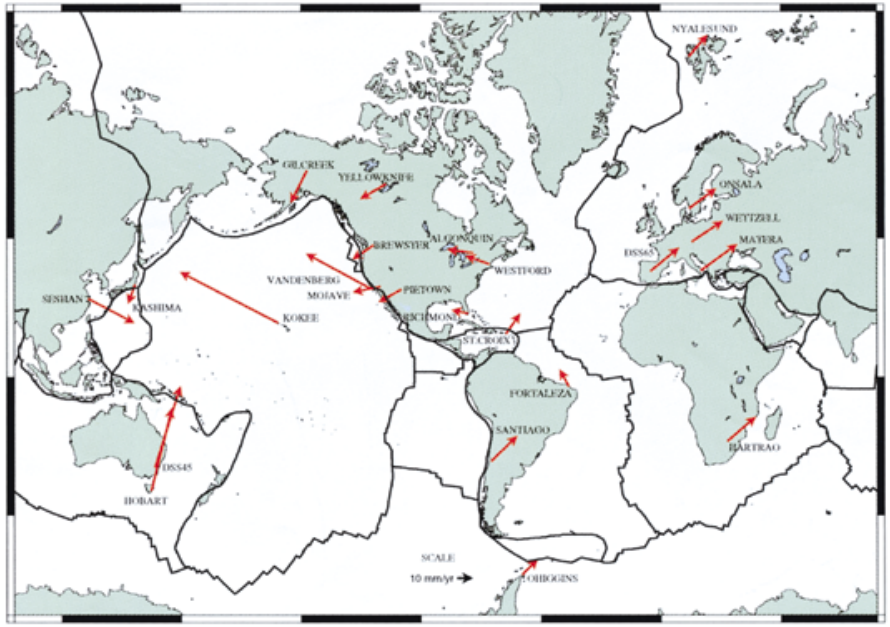
- Highest resolution technique available to astronomers – tens of microarcseconds
- Allows detailed studies of the most distant objects

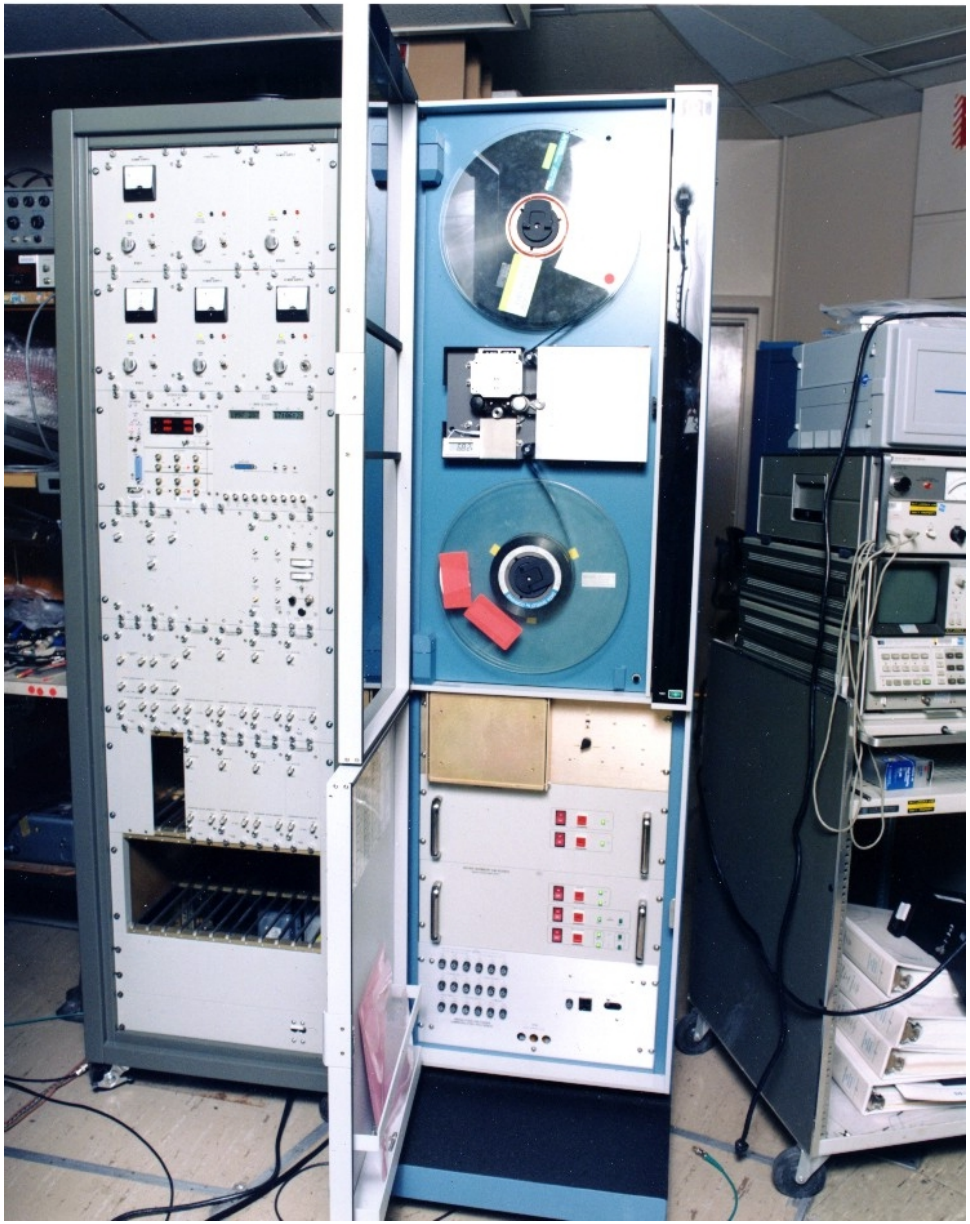


GEODESY

- Highest precision (few mm) technique available for global tectonic measurements
- Highest spatial and time resolution of Earth's motion in space for the study of Earth's interior
  - •Earth-rotation measurements important for military/civilian navigation
  - •Fundamental calibration for GPS constellation within Celestial Ref Frame

Plate-tectonic motions from VLBI measurements





Typical VLBI tape recording system

16-station VLBI correlator at JIVE in The Netherlands

Scientific Advantages of e-VLBI

- Bandwidth growth potential for higher sensitivity
  - VLBI sensitivity (SNR) proportional to square root of Bandwidth resulting in a large increase in number of observable objects
    (only alternative is bigger antennas – hugely expensive)
  - e-VLBI bandwidth potential growth far exceeds recording capability
    (practical recordable data rate limited to ~1 Gbps)
- Rapid processing turnaround
  - Astronomy
    - Ability to study transient phenomena with feedback to steer observations
  - Geodesy
    - Higher-precision measurements for geophysical investigations
    - Better Earth-orientation predictions, particularly UT1, important for military and civilian navigation

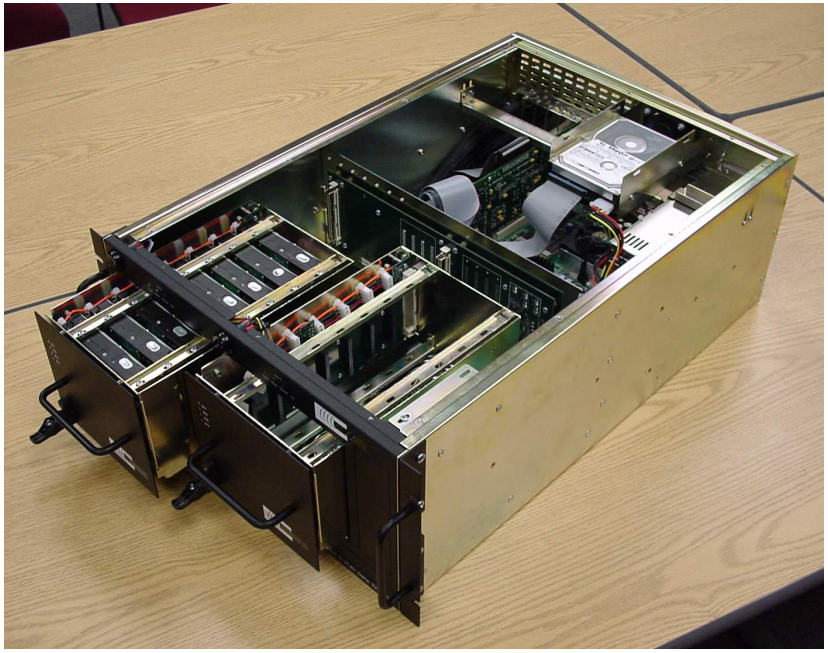
Practical Advantages of 'e-VLBI'

- Increased Reliability
  - remove recording equipment out of field
  - remote performance monitor & control capability in near real-time
- Lower Cost
  - Automated Operation Possible
    - eliminates manual handling and shipping of storage media
  - Near Real-time Processing
    - forestalls growth of storage-capacity requirements with bandwidth growth
  - Elimination of recording-media pool (millions of $'s!)
- Avoid unexpected media-shipping interruptions and losses

Elements of e-VLBI Development

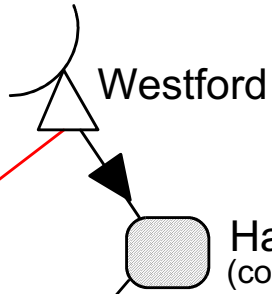
- Phase 1: Develop eVLBI-compatible data system
  - Mark 5 system development at MIT Haystack Observatory being supported by NRAO, NASA, USNO plus four international partners
  - Prototypes now deployed in U.S. and Europe
- Phase 2: Demonstrate 1 Gbps e-VLBI using Bossnet
  (w/ DARPA and NASA support)
  - ~700km link between Haystack Observatory and NASA/GSFC
  - First e-VLBI experiment achieved ~788Mbps transfer rate
- Phase 3: Establish 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
  - Connect with telescopes worldwide (U.S., Europe, Japan)

Mark 5 VLBI Disk-Based Data System (Phase 1)



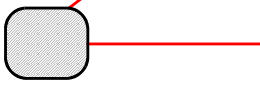
- 1 Gbps continuous recording/playback to/from set of 8 inexpensive (ATA) disks
- Developed at MIT Haystack Observatory with multi-institutional support
- Mostly COTS components
- Two removable '8-pack' disk modules in single 5U chassis
- With currently available 200GB disks – capacity of single '8-pack' 1.6TB; expected to increase to 2.5TB by early 2003 at cost of ~$1/GB
- GigE connection for real-time and quasi-real-time e-VLBI operations
- Inexpensive: <$20K
- ~20 Mark 5 systems now installed at stations and correlators

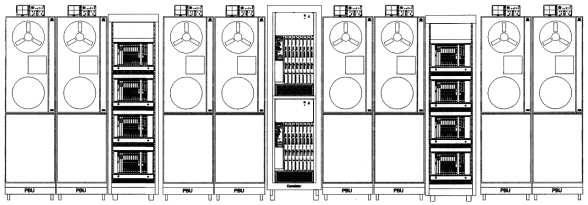
Bossnet 1 Gbps e-VLBI demonstration experiment (Phase 2)



Future

Initial experiment





Details of path from Haystack to ISI-E – work in progress!

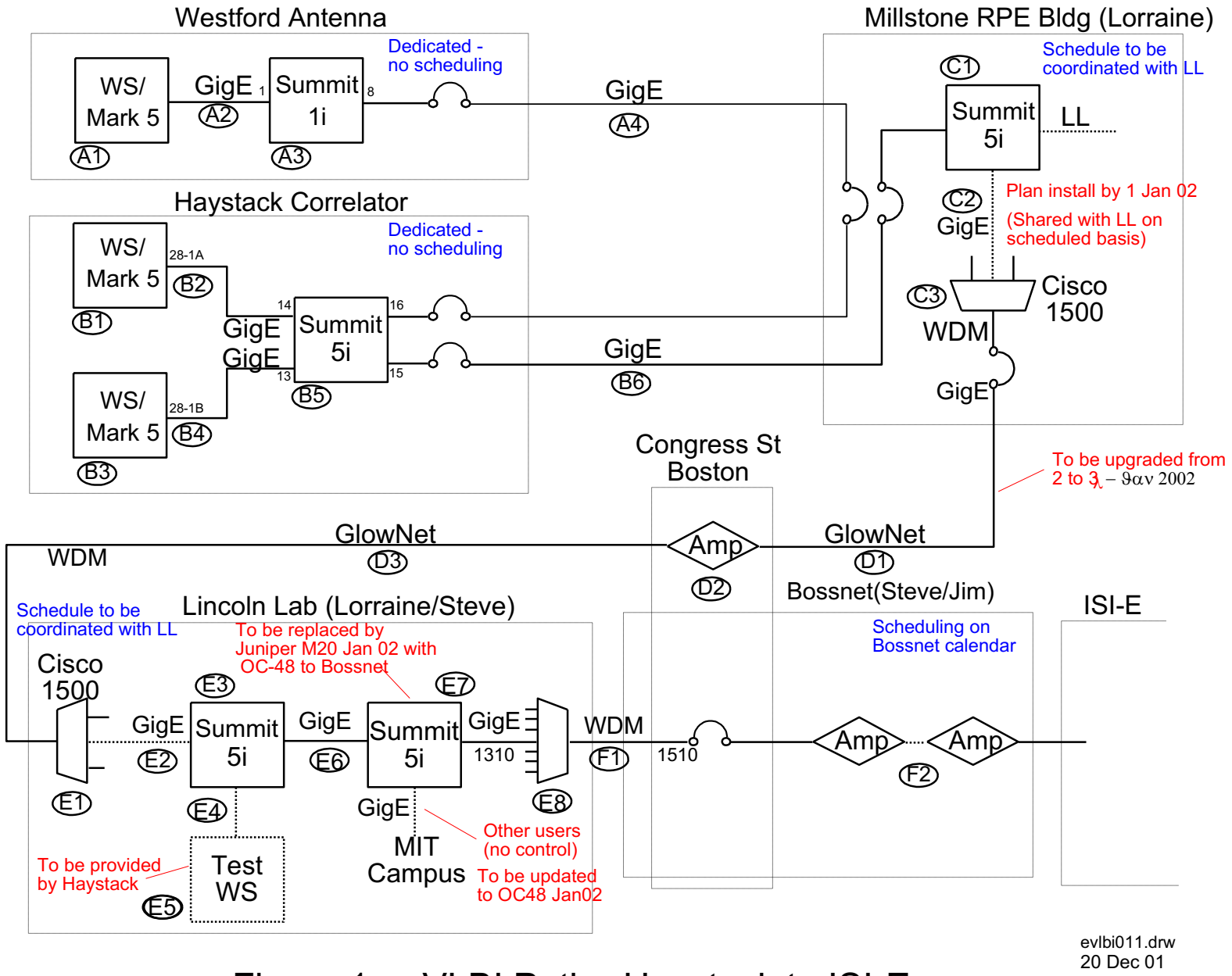


Figure 1: e-VLBI Path - Haystack to ISI-E

Details of path from ISI-E to GSFC Antenna – work in progress

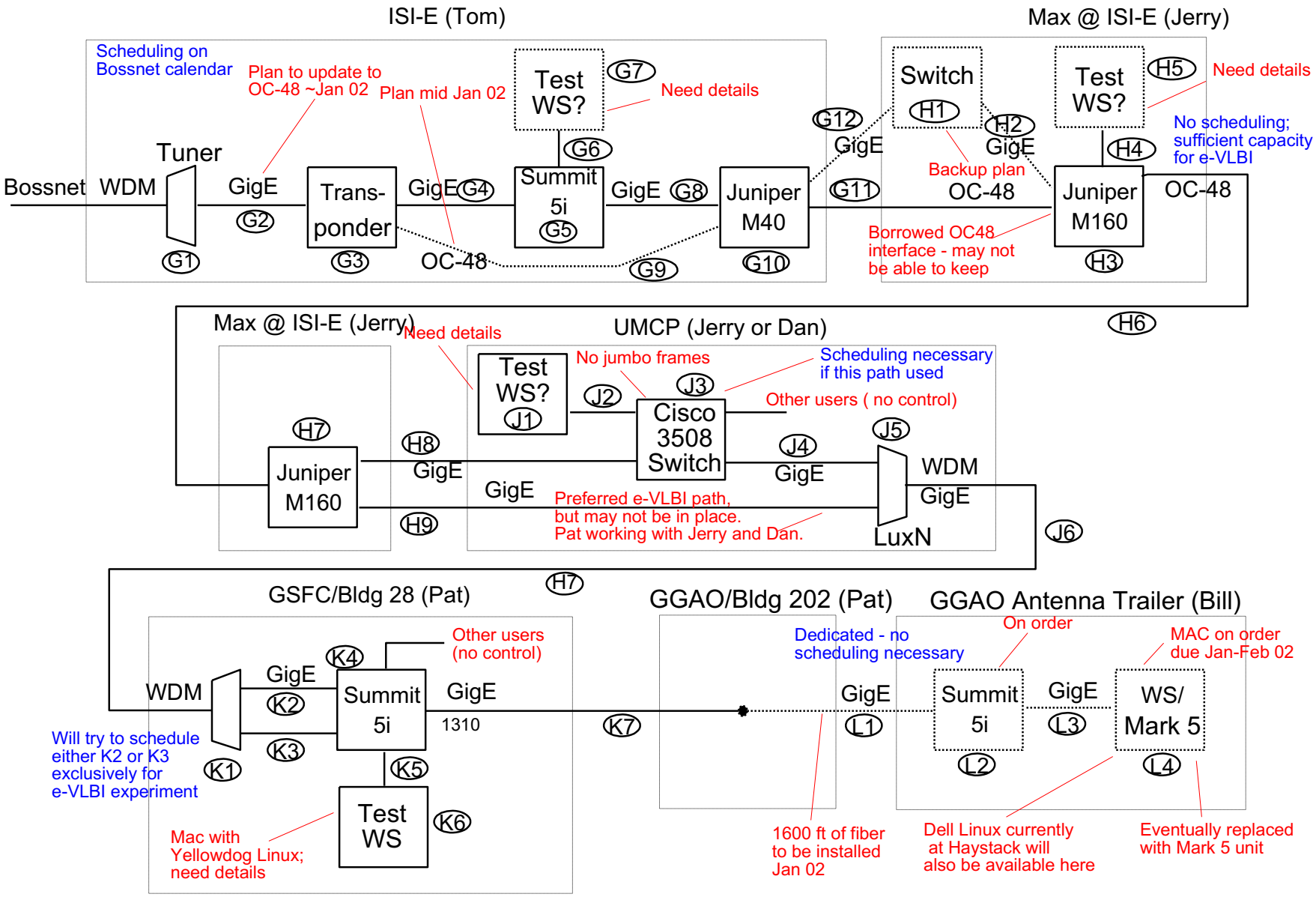
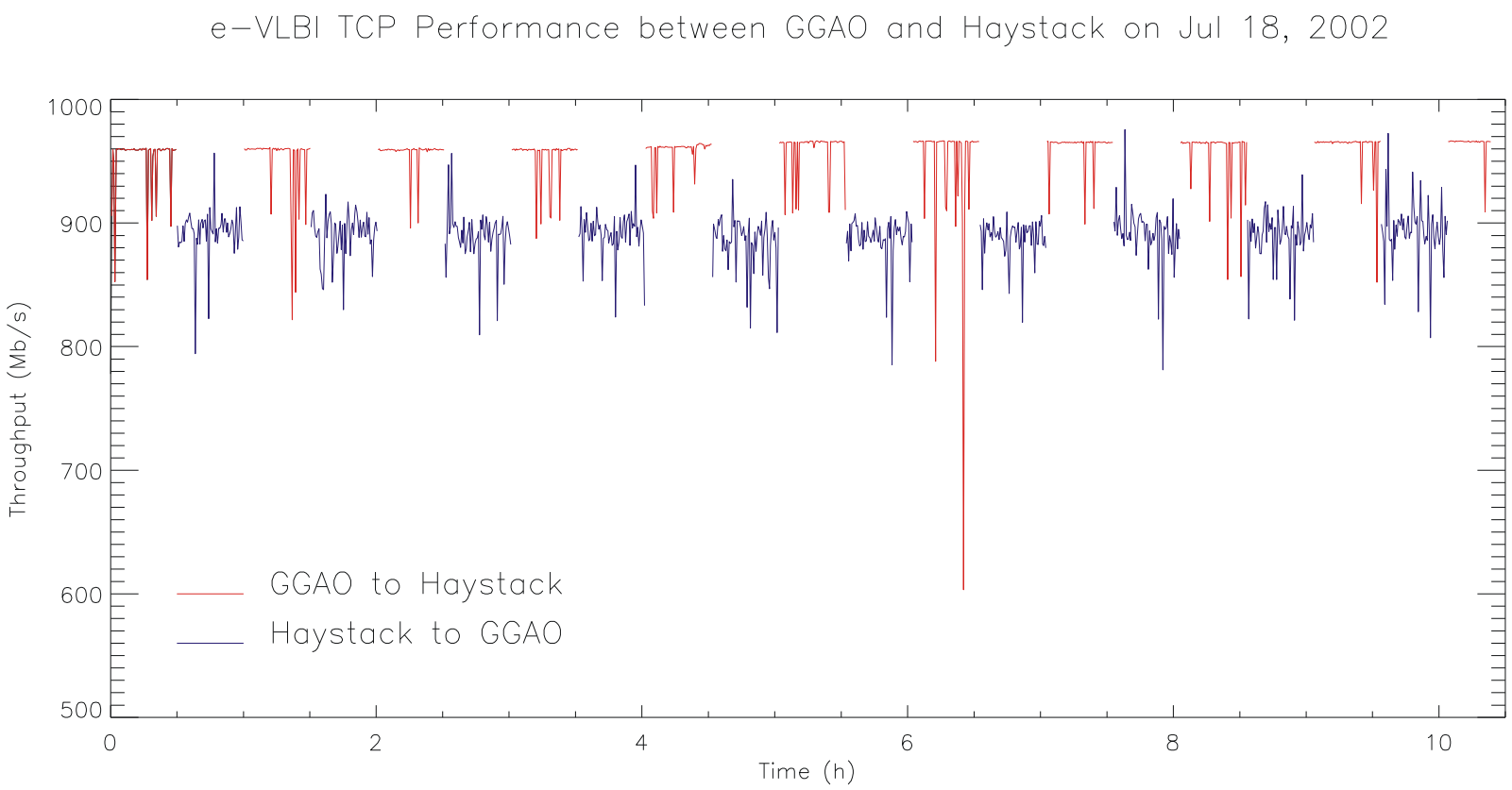


Figure 2: e-VLBI Path - ISI-E to GSFC/GGAO

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

Westford-to-Kashima e-VLBI experiment

- Westford/Kashima experiment conducted on 15 Oct 02
  - Data recorded on K5 at Kashima and Mark 5 at Westford at 256 Mbps
  - Files exchanged over Abilene/GEMnet networks
    - Nominal speed expected to be ~20 Mbps, but achieved <2 Mbps for unknown reasons - investigating
  - File formats software translated
  - Correlation on Mark 4 correlator at Haystack and PC Software correlator at Kashima
  - Nominal fringes obtained
  - Further experiments are anticipated

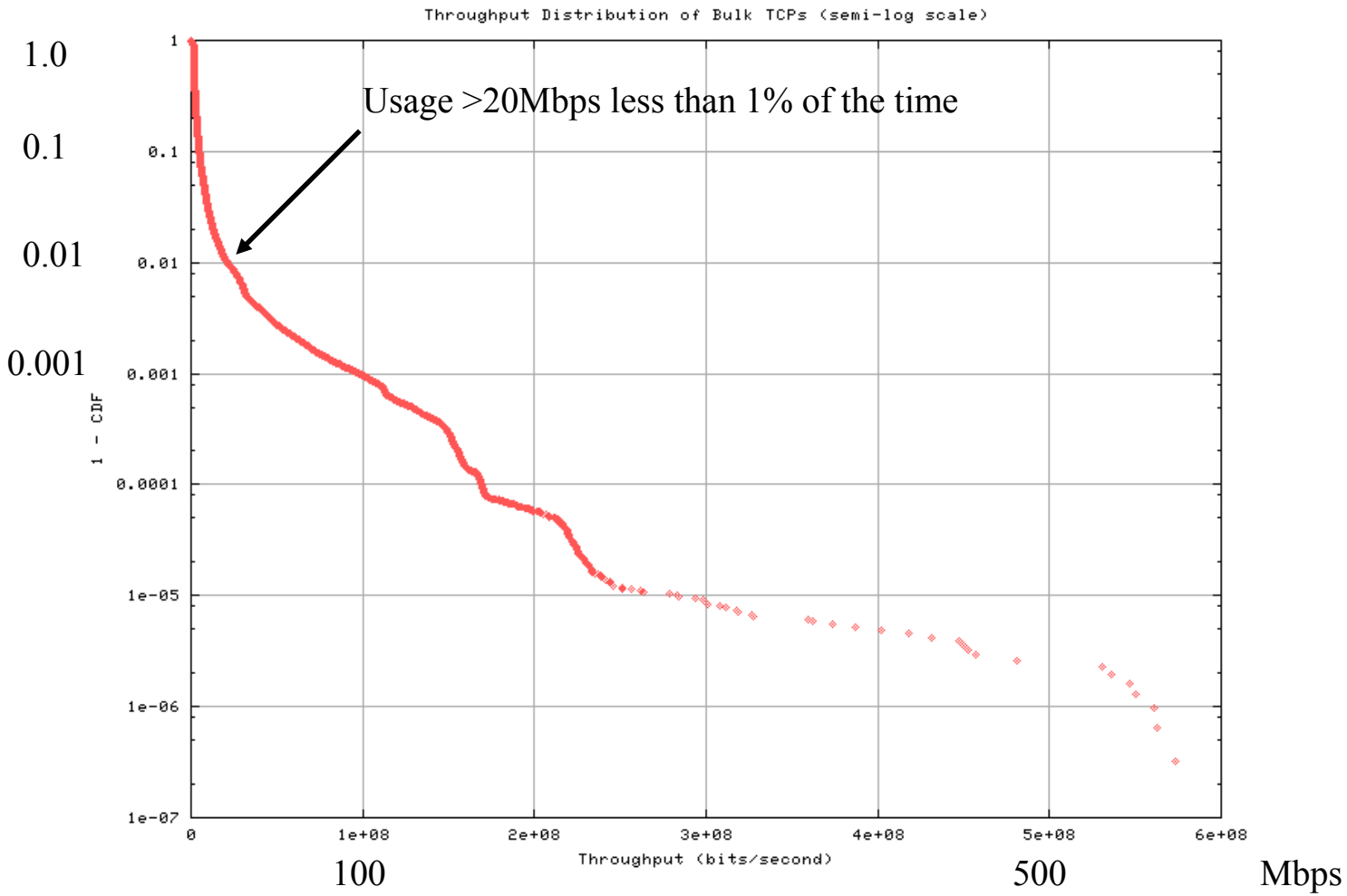
Plans for UT1 Intensive e-VLBI

- Daily ~1 hour VLBI sessions between Kokee Park, Hawaii and Wettzell, Germany are used for UT1 measurements
- Data are time sensitive since they are used for predicting UT1
- Currently requires ~4 day turnaround shipping media
- These measurements are an ideal candidate for routine e-VLBI
  - Short daily session collect <100 GB of data
  - Even 100 Mbps will allow transfer in a few hours
- Work now in progress to make necessary connections
  - Network being organized from Kokee Park to USNO; connection speed OC-3
  - Data from Mark 5 system in Wettzell will be carried to Univ. of Regensberg, about 1 hour drive; connection speed OC-3
  - Negotiations ongoing for extension of MAX network to USNO with GigE connection

New IP Protocols for e-VLBI (Phase 3)

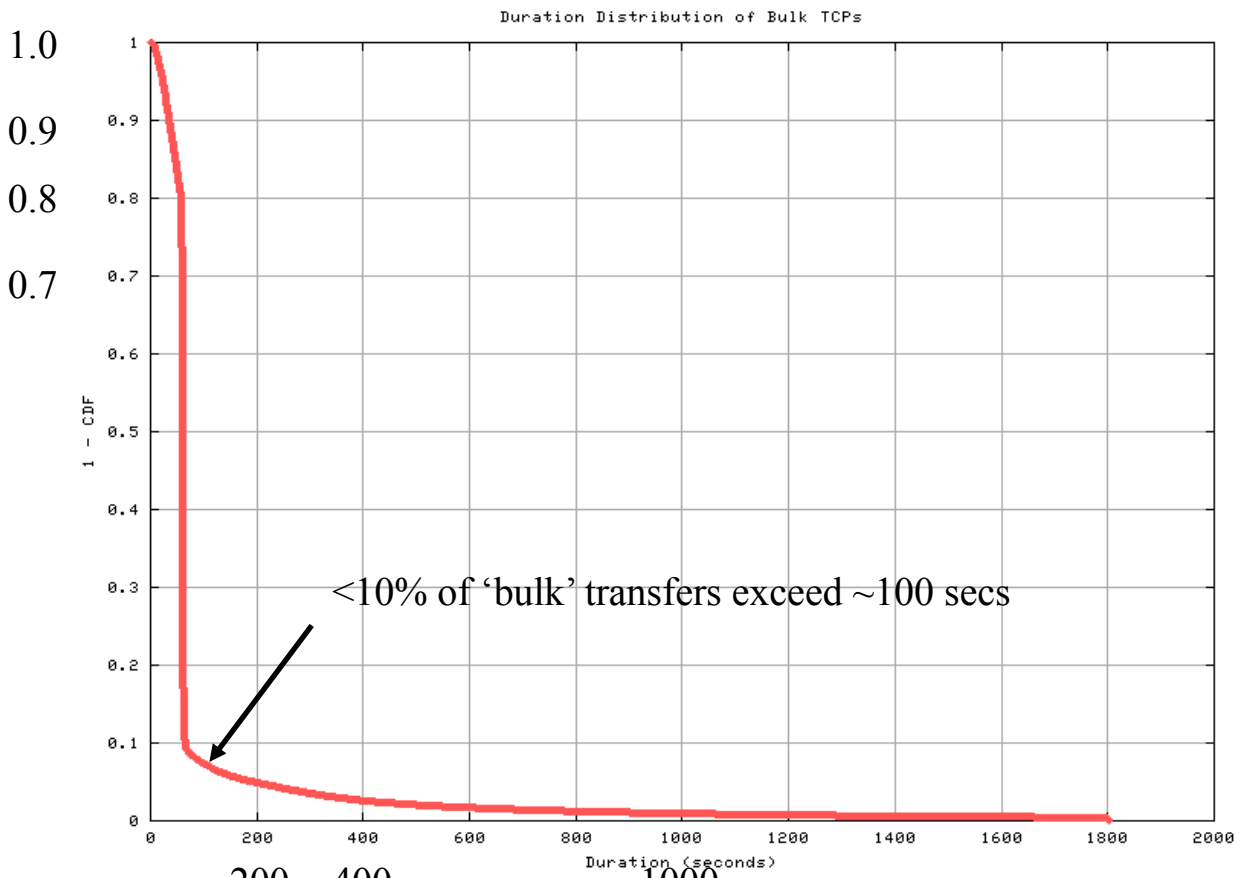
- Based on observed usage statistics of networks such as Abilene, it is clear there is much unused capacity
- New protocols are being developed to utilize networks in 'background' mode for applications such as e-VLBI
  - Take advantage of special characteristics of e-VLBI data
  - Will 'scavenge' and 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

Typical bit-rate statistics on Abilene network



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

Typical distribution of heavy traffic on Abilene



1.0

0.9

0.8

0.7

200 400 1000 secs

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

Impact of e-VLBI Program

- Opens new doors for astronomical and geophysical research.
- Represents an excellent match between modern Information Technology and a real science need.
- Motivates the development of a new shared-network protocol that will benefit other similar applications.
- Drives an innovative IT research application and fosters a strong international science collaboration.