Haystack Observatory Technology Development Center

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Abstract

VLBI technology development at Haystack Observatory continues to focus on VLBI data recording and transport. With the completion of the Mark 5A disk-based data-recording system and its subsequent widespread deployment (~80 units now in operation), engineering efforts are now focused on developing the Mark 5B, which uses the same platform and media as Mark 5A, but which will comply with the VSI specification. Additionally, a major program continues to focus on e-VLBI development, including the development of VSI-E, new protocols and algorithms, performance testing and monitoring, and the beginnings of routine e-VLBI transfers.

1. Mark 5B VLBI Data System

The Mark 5B VLBI data system is now being developed at MIT Haystack Observatory. It is based on the same physical platform, uses the same disk-modules as the Mark 5A, and supports the same maximum data rate of 1024 Mbps. However, the Mark 5B will incorporate a VSI standard interface and command set. The Mark 5B system may be used with a Mark 4 or VLBA data-acquisition rack with the use of simple interface electronics connecting directly to the Mark 4 or VLBA samplers, eliminating the need for an external formatter. For existing VLBA systems using VLBA formatters, the current recording limit is 512 Mbps due to formatter limitations; the use of a Mark 5B connected to the sampler outputs will allow the recording of 1024 Mbps. For existing Mark 4 systems, the Mark 5B will allow connection of all 14 BBCs to two Mark 5Bs for a total aggregate data rate of 1792 Mbps. A backwards compatibility path will be provided to allow disks recorded on the Mark 5B system to be replayed on a Mark 5A system with the output in VLBA tape-track format. This will allow existing Mark 4 correlators to process Mark 5B data. An upgrade to existing Mark 5A systems will be made to implement this compatibility path.

In addition, the Mark 5B is being designed to emulate all critical functionality of the Mark 4 Station Unit, so that the Mark 5B may be directly connected to a Mark 4 correlator through a simple interface without the use of a Mark 4 Station Unit. This will allow existing Mark 4 correlators to inexpensively expand the number of stations they support. Prototype Mark 5B systems are expected to be available in late 2004.

2. e-VLBI Development

Haystack Observatory continues to develop the e-VLBI technique with a broad spectrum of efforts, including:

- VSI-E draft: After many months of fine tuning, the first VSI-E draft specification was distributed for discussion within the community. After a general consensus at the VLBI workshop in Dwingeloo that the RTP based framework would provide many advantages to the VLBI community, networking and astronomy researchers have been working to come up with a strawman solution that will be acceptable to both communities: meeting the requirements of the application while doing so in a manner that is efficient and network "friendly". The framework provides signaling, control, framing and statistics support and is an extension to

the Internet standard RFC3550. It also provides flexibility in that it allows users to choose the transport protocol that most suits their networking environment (e.g. UDP, TCP or other variants).

- New connections to Wettzell and Kokee: Wettzell has recently installed a new E3 (34 Mbps) link to the University of Regensberg, which connects to the German Federal Network (DFN) and then the pan-European GEANT research network. Researchers at Wettzell, Hawaii and Haystack have been actively involved in testing this link and are looking forward to being able to utilize it to support Intensive experiments using e-VLBI. In Hawaii, a new OC3 link has been installed on Kauai between PMRF and Kokee Park. This has increased the bottleneck bandwidth from $\sim$ 5 Mbps to $\sim$ 80 Mbps. A series of experiments are planned that will use this bandwidth for the support of Intensive experiments.
- Regular data transfer from Kashima: Starting in October 2003, data from all of the sessions at the Kashima 34 m antenna have been recorded in K5 format and transferred to Westford via e-VLBI. The data were converted to Mark 5 format and then stored on Mark 5 disk pack before being sent for correlation on Mark 4 correlators. Thanks to the efforts of many people at CRL, USNO and Haystack the data were transferred successfully and fringes were detected for two of the experiments transferred so far. Sessions CRF22, CRF23 and T2023 were all transferred using e-VLBI. The data were transferred from Kashima to Westford using BBFTP and special software to automate the transfer to a performance server at Haystack and then to a Mark 5 8-pack. The main purpose of this transfer was to verify the feasibility and automation software. The data rates for the sessions were relatively low, as the path they were traversing was bandwidth limited. It is expected that in the near future the path bandwidth will be significantly increased as part of a network upgrade. Session CRF22 involved the transfer of 442 GB of data at 11.02 Mbps using 4 parallel TCP streams. Session CRF23 involved the transfer of 489 GB of data at 11.8 Mbps using 4 parallel TCP streams. Session T2023 involved the transfer of 543 GB of data at 33.6 Mbps using 8 parallel TCP streams.
- Automated data transfers: As part of an ongoing effort, work is continuing on the development of toolkits for helping to automate the transfer of VLBI data across Wide Area Networks. This effort has resulted in tools that allow users to efficiently transfer large volumes of data between Mark 5 units and PCs across LANs as well as MANs.
- DRAGON: Researchers at Haystack have recently started a new project, the Dynamic Resource Allocation through GMPLS over Optical Networks (DRAGON) in collaboration with the University of Maryland Mid-Atlantic Crossroads (MAX), Univ. of S. California Information Sciences Institute, George Mason Univ., NASA/GSFC and USNO, and industry partner Movaz Networks. This project features e-VLBI as one of its premier applications and will provide advanced optical switching infrastructure for supporting e-VLBI experiments.
- Performance and testing: Haystack has been working in close collaboration with Internet2 on the development of an automated performance tool, BGPerf. Ali Lotia and Charles Yun from Internet2 have developed a tool that automates the secure initiation and tear-down of "iperf" flows ("iperf" is a widely used network bandwidth measurement and estimation tool). Network performance tests with BGPerf are ongoing. BGPerf automates logging and timestamping of results, secure initiation of connections between clients and servers and

resource usage limitation. It will soon include support for a database back end, multiple performance tools and parsing of output files to extract higher order performance results. Haystack has also developed a performance site for monitoring qualitative performance using existing tools such as MRTG, Smokeping, etc.

- Measurement and protocol testing: Network performance characterization and protocol testing between various e-VLBI sites around the world continues. Tests within the United States, Japan, South America and Europe are ongoing. Recent results have demonstrated 360 Mbps disk-to-disk throughput using advanced transfer protocols and servers located in Tokyo, Japan and at Haystack.
- EGAE: Researchers at Haystack continue to work on the Experiment Guided Adaptive Endpoint (EGAE). This protocol will provide the interface between a VSI data acquisition system and the network. It will implement the RTP-based VSI-E protocol. Current experiments include looking at the suitability of various transport protocols (e.g. TCP, High speed TCP, SABUL, TSUNAMI, etc.) for use within this framework and how best to integrate these protocols into the EGAE.

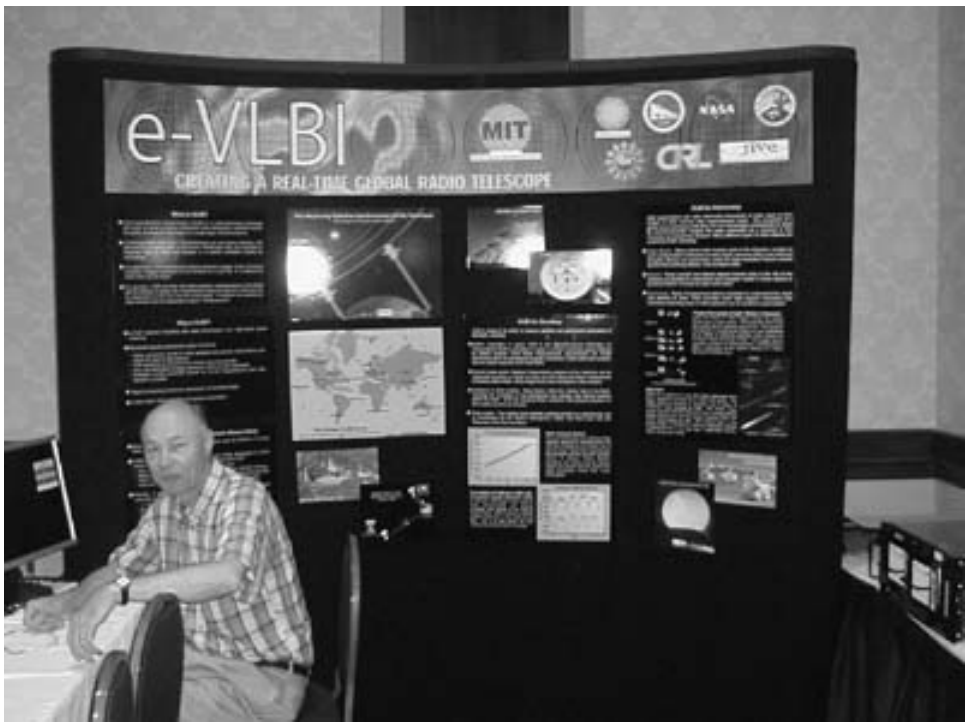

Figure 1. e-VLBI display at Internet2 meeting in Indianapolis, October 2002.

- Internet2 e-VLBI demonstration: An e-VLBI demonstration was given at the Internet2 Fall members meeting in October 2003 in Indianapolis. The demonstration was highly successful in raising awareness of VLBI and e-VLBI. In the demonstration area, a large display was constructed which described VLBI, e-VLBI, participants in VLBI and the application of VLBI to astronomical and geodetic applications. Two Mark 5 units were located in the

demonstration area, both connected via optical fiber into a dedicated 1 Gbps stream that was connected into Abilene via a shared 10 Gbps trunk. Three laptop computers were used to display animations obtained from VLBI observations, video footage of the Westford telescope taken during a geodetic observing session and a real-time display of the application transport statistics. A demonstration was given of the transfer of VLBI data between the US and another International site using prototype RTP software. A demonstration was also given of the transfer of VLBI data between two Mark 5 systems located in the US. A maximum throughput of 207 Mbps was achieved. Demonstrators were also able to test memory to memory transfers between various sites and achieve a maximum TCP throughput of 460 Mbps using FAST TCP, 180 Mbps using TCP Reno and 400 Mbps using High Speed TCP. Sincere thanks go to the following institutions for their help and participation in this demonstration:

- Arecibo Observatory, National Astronomy and Ionosphere Center of Cornell University, Puerto Rico
- Australia Telescope National Facility, Commonwealth Scientific and Industrial Research Organisation, Sydney, Australia
- Communications Research Laboratory, Kashima, Japan
- Goddard Geophysical and Astronomical Observatory, Goddard Space Flight Center, NASA, Greenbelt, MD
- Joint Institute for VLBI in Europe, The Netherlands
- MIT Haystack Observatory, Westford, MA
- Smithsonian Astrophysical Observatory (Submillimeter Array), Mauna Kea, HI