Future directions in VLBI technology

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Three technology areas are examined to measure their impact on VLBI and the capabilities that may be offered to VLBI practioners in the near future:

VLBI Standard Interface: An international committee has recently agreed on a standard interface definition for all future VLBI data systems. This should, at long last, allow interoperability between various VLBI data systems.

New Recording Technologies: Courtesy of large investments by the computer industry, moderately priced high-data rate digital recorders that may be suitable for VLBI are on the near horizon. Small arrays of these machines, appropriately interfaced, promise to support 1-8 Gbps recording over the next few years at an attractive price.

e-VLBI: With the advent of optical fiber being laid at a prodigious rate, real-time (or near-real time) VLBI on an international scale is close to being a technical possibility. However, questions remain about costs to lease the necessary bandwidth and to lay the 'last mile' of fiber to remote antennas.

1. VLBI Standard Interface

The incompatibility of various VLBI data systems has long been recognized as posing a serious obstacle to the realization of the full potential of VLBI observations. Sporadic efforts have developed over the years to define a common interface standard which would allow observations recorded on different VLBI data systems to be processed at a common correlator, but these efforts have foundered for various reasons.

The establishment of the Global VLBI Working Group (GVWG) in the early 1990's, growing primarily from the space-VLBI community but serving the broader interests of astronomy, and the International VLBI Service (IVS) in 1998, serving primarily the geodetic VLBI community, provided an organizational framework for which efforts at standardization could proceed in a more organized and sanctioned fashion. It was from these roots that the present effort was initiated.

The fledgling VSI concept leading to the current specification was first proposed at the time of the GEMSTONE meeting in Tokyo in January 1999 and was discussed by a small interested group at that meeting. Support was then sought and received from IVS and GVWG to create a VSI Technology Coordination Group (VSI-TCG) comprised of experts representing all of the major world institutions involved in the development of VLBI equipment. The members of this committee are Wayne Cannon (York University/Crestech, Canada), Brent Carlson (DRAO, Canada), Dick Ferris (ATNF, Australia), Dave Graham (MPI, Germany), Tetsuro Kondo (CRL, Japan), Nori Kawaguchi (NAO, Japan), Misha Popov (ASC, Russia), Sergei Pogrebenko (JIVE, Netherlands), Jon Romney (NRAO, U.S.), Ralph Spencer (Jodrell, England), Alan Whitney (Haystack, U.S., Chairman) and Rick Wietfeldt (JPL, U.S.).

Early in the discussions it was decided to separate the hardware and software VSI, concentrating first on hardware, known as the VSI-H specification, to be followed by a companion software specification, VSI-S. The VSI-H specification was shaped by intensive e-mail discussions, plus three (multi-hour!) international telephone conferences and a two-day international VSI meeting held at Haystack Observatory in February 2000.

The VSI-H specification is based on the following set of assumptions:

• The VLBI Data Transmission System (DTS) is fundamentally a receiver and transmitter of parallel bit streams between a Data-Acquisition System and a Data Processing System.

• The meaning of individual bit streams is not specified; normally, a bit-stream is a stream of sign or magnitude bits associated with particular samples, but the actual meaning is to be mutually agreed upon between the DAS and DPS.

• The received and transmitted bit-stream clock rates may be different (e.g. the playback rate into the DPS may be speeded-up or slowed-down), however all received bit-stream information rates on acquisition are the same, and all bit-stream clock rates on transmit are the same.

• A single time-tag applies to all parallel bit streams. The DAS time-tag of every bit in every bit-stream must be fully recoverable at the output of the DTS.

Under these assumptions, no restrictions or specifications are placed on the type or format of the medium used to transport the data through the DTS; magnetic tape, disk, optical fiber, Internet or any other type of transmission medium is allowed. Furthermore, the VSI-H specification is independent of channel bandwidth, with the expectation that channel bandwidths will probably increase substantially in the future.

Figure 1 shows a simplified functional block diagram of a VSI-compliant VLBI DTS. A set of parallel bit streams are provided to the DTS by the Data Acquisition System (i.e. samplers). The DTS has the responsibility to time-tag and store this data in any manner it sees fit, so long as it is able to faithfully reproduce the same bit streams on demand at the output of the DTS. Provisions are included in the VSI-H specification to maintain the necessary timing relationships at both the input and output of the DTS. A full set of test vector generators and receivers is specified in order to test that the interfaces are working properly. The full 30-page VSI-H specification is available online at http://fourier.haystack.mit.edu/haystack/vlbi.html.

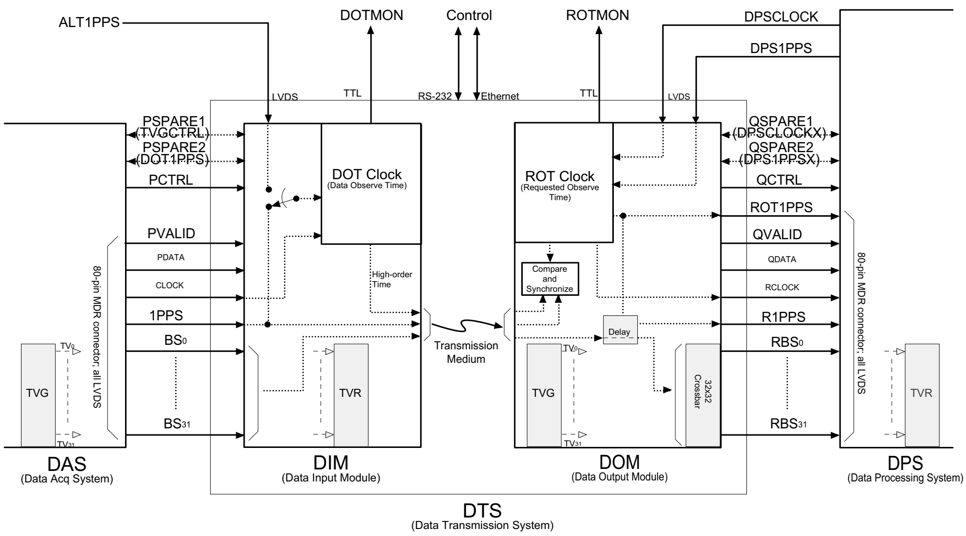

Figure 1: VSI-H Functional Block Diagram

The VSI-H specification defines a basic 'channel quantum' of 1.024 Gbps. Any number of 'channel quanta' may be implemented in a specific design, so that no limits are placed on the total data throughput rate of a DTS.

The current VSI-H specification is intended as a starting point from which to progress, and will be extended and amended as requirements and technology demand. Already at least three groups are known to be developing or adapting VLBI data systems to meet the VSI-H standard.

2. New Recording Technologies

Recent and continuing developments of magnetic-tape data-storage systems for the computer industry provide a basis on which to create a high-performance, affordable high-data-rate VLBI recording and playback systems.

Figure 2 shows the historical progression of the native storage capacity of a single tape for several commercial systems, both of the helical scan and linear variety, and all of which use a tape cartridge format. Also shown is the industry projection for storage capacity over the next 7-8 years. We note that today's single-tape capacity of roughly 100 GB is expected to rise to 1 TB by 2007; capacities of 0.5 TB/tape have already been demonstrated in commercial laboratories. Though projecting future technology is clearly a risky business, some credibility to these projections may be gained by noting that the disc drive industry has handily outstripped nearly all predictions made for that industry over the past 5 years; tape technology is quickly picking up steam and is now beginning to move very aggressively in the same direction.

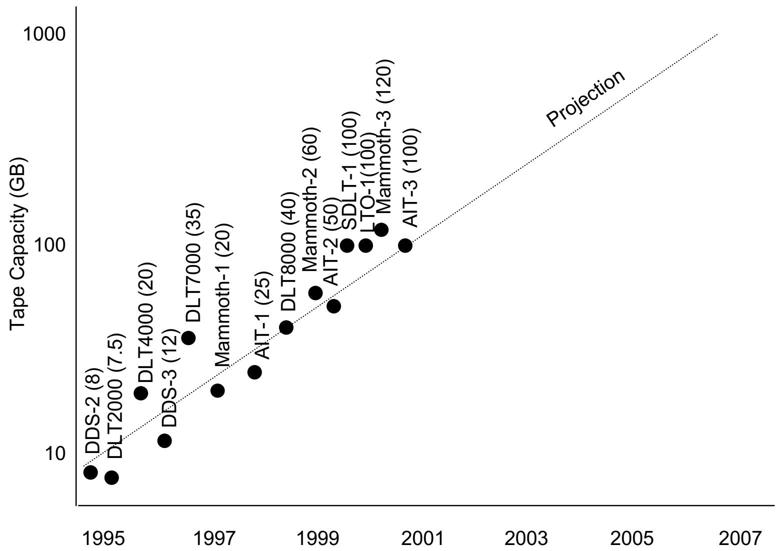

Figure 2: Tape Capacity vs. Time

Figure 3 shows the history of single-drive data rates for the same set of systems, as well as industry projections for single-drive data rates over the next 7-8 years. The currently available data rates of 10-12 MB/sec will rise to 16-18 MB/sec in announced products available within the next 4-8 months, and are expected to rise to the order of 128 MB/sec/drive by 2007, roughly mirroring the growth rate of data storage capacity.

Current costs of a single tape drive, regardless of type, is on the order of $7-10K each in small quantities. Based on past experience and on industry projection, the cost per drive will remain relatively constant as the technology progresses over the next 7-8 years.

These tape systems are computer grade systems with high-reliability and extremely low error rates due to extensive use of error-correcting codes and redundancy. Though

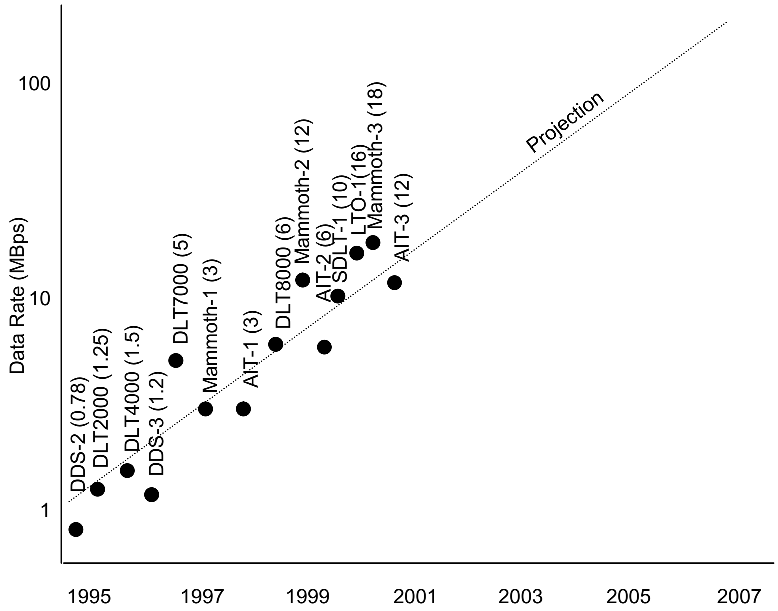

Figure 3: Tape Data-Rate vs. Time

such low error rates are not needed for VLBI, the costs of circumventing such error-correcting codes to gain higher data rates and capacities is probably not worth the effort or cost.

Whatever the details of the tape technology to be used, whether linear or helical-scan or something else, the implications are clear. Within the next year, 8 standard commercial tape drives at 16 MB/sec each can, in principle, be paralleled to achieve 1 Gbps data rate for an investment of <$80K in tape drives. In 7-8 years, as shown in Figure 2, a single tape drive is expected to be capable of 1 Gbps (128 MB/sec), so that a bank of 8 such machines will be able to achieve 8 Gbps for the same <$80K investment in tape drives!

VLBI data systems based on these commercial tape systems should be based on mostly-off-the-shelf hardware which is readily available from the computer industry, with a minimum of custom design, and which can easily grow to higher data rates as the recording industry advances. Furthermore, they must be capable of unattended operation for at least 24 hours. Based on currently-announced tape products and projected industry roadmaps, the cost per Gbps for such systems will drop from a Year 2000 cost of $100K/Gbps to $14K/Gbps by 2007 . This suggests that VLBI data systems in the range of 8 Gbps may be available for <$150K before the end of this decade.

3. e-VLBI

Electronic transmission of VLBI data is attractive for several reasons:

- Improve system reliability by reducing or eliminating dependence on tapes
- Rapid results to help direct focus on short-term astronomical events
- Monitor, test, debug station in near real-time for improved data reliability
- Full station automation (i.e. no tape changes) to reduce operational costs

The world is being rapidly wired commercially with high-speed optical fibers between virtually all major population centers. Projections by various 'experts' indicate 'surplus' bandwidth sufficient to accommodate VLBI needs at multi-Gbps data rates. There are, however, a few obvious problems:

• The 'last mile' problem: Many, if not most, radio telescopes in the world have been deliberately built away from population centers, therefore the 'last mile' problem to connect to these stations is a significant hurdle. The minimum cost to lay fiber is estimated to be $10/meter ($10K/kilometer) under the most optimistic and benign conditions. Therefore, the minimum cost to connect a station 100 km from a major connection point is $1M. Connection within densely populated regional areas, such as Europe and Japan, is probably practical since 'last mile' distances tend to be relatively small. But connections to remote sites in other parts of the world, such as China, South America, Australia and even to some degree in North America, will be quite expensive compared to several-year's operation of conventional recording systems.

• Everyone must be connected: This is so obvious as to hardly need stating, but a real-time network cannot succeed unless every telescope of interest is connected. The failure of even one critical station to be connected will force a fallback to conventional VLBI recording. For conventional recording, the cost/station is roughly independent of station. For e-VLBI, the capital costs are highly variable and will be significant burdens on certain stations or institutions unless some cost-sharing arrangement is worked out within the VLBI community. It is heartening to observe the European VLBI community moving in this direction to connect European stations.

• Long-haul commercial leasing costs are high: An informal survey of commercial costs in 1998 indicated the cost of a dedicated T1 line (1.5 Mbps) across that Atlantic Ocean to be anywhere from $30K-60K per month. A similar survey conducted in 2000 showed only a relatively small decrease in these costs. It seems relatively clear that long-haul communications costs, based on commercial rates, will not be competitive with magnetic recording costs for many years, if ever. The communications companies have invested many billions of dollars in creating these infrastructures and expect a fair return on their investment. On the other hand, it may be possible for governments, or international consortia of governmental institutions, to approach the global communications companies and propose experimental research use of surplus capacity for a nominal or no charge. This will require good organization and persuasive arguments at the highest levels among international VLBI institutions and their sponsoring government agencies.