VLB ARRAY MEMO No. 661

USER INTERACTION WITH THE VLBA

R. C. Walker and J. D. Romney
April 3, 1990

Among the major goals of the VLBA project are to enhance the quality and reliability of VLBI observations compared to what has been available with the existing VLBI Networks, and to increase greatly the accessibility of VLBI observations to non-specialists. These goals require not only high quality hardware but also that the instrument be operated in a "user friendly" manner. At the time the Array was proposed, a concept of how the user would interact with the instrument, and what standard products would be delivered to the user, was presented (see "A Program for the Very Long Baseline Array Radio Telescope", May 1982 — the VLBA "Red Book" proposal). That concept has changed very little through the years of construction and early operation and is still considered to be reasonably current. Partly because there have been few changes, there is very little more recent documentation of the operating concepts.

As we now ramp up the actual Array operations and look forward to starting stand-alone observing within a couple of years, using the first six or seven stations and the VLBA correlator, perhaps the time has come to lay out clearly the plan for user interaction with the final instrument. This document is an attempt to do that. It includes some new material arising from numerous discussions at international scientific meetings during 1988 and 1989, and was motivated largely by a long list of questions and suggestions sent by R. W. Porcas prior to the March 1990 meeting of the VLBA Scientific Advisory Committee.

The basic steps of interaction between the user and the VLBA are outlined below.

PROPOSING

Observations will be proposed in a manner very similar to current practice on the VLA and the VLBI Networks. The user will write a proposal containing technical information about the requested observations, a source list including requested sidereal time intervals, and a scientific justification. NRAO may provide software for calculation of sidereal time, but this is of low priority in view of the wide availability of appropriate software from other sources. Proposals will be considered at specific times of the year for which deadlines will be announced.

A first call for proposals to use currently operational VLBA stations was issued in NRAO Newsletter No. 39, dated 1989 April 1, with deadlines coinciding with the VLA deadlines. As the VLBA takes over from the U. S. VLBI Network, it would be useful for the VLBA deadlines to coincide also with the European VLBI Network deadlines. In both cases there are three deadlines annually, offset at present by only 2 weeks, so aligning them should not be a major problem.

One question that needs to be addressed is how to handle proposals involving many non-VLBA stations. Already, VLBA proposals can request the VLA without a separate VLA proposal, and presumably this will be extended to any other NRAO telescopes such as the 140-Foot or the Green Bank Telescope. However, non-NRAO organizations will surely want to participate in some way in the refereeing and scheduling of larger projects using their instruments. Current practice is to submit proposals to the U. S. and European Networks requesting Network telescopes (including those operated by NRAO) and to submit separate proposals to non-Network telescopes. Most stations of the U. S. Network will be replaced effectively by the VLBA and other NRAO facilities, leaving a remnant probably insufficient to sustain Network operations. With the construction of new antennas for VLBI occurring in many countries beyond the scope of the U. S. and European Networks, perhaps it is time to consider forming an organization whose primary purpose is to coordinate global observations.

REFEREEING

VLBA proposals will be refereed in a manner very similar to VLA proposals. As with the VLA, the number of proposals is expected to be too large for all to be sent to every referee. It is also desirable that a proposal be refereed primarily by people who know something about the specific field being addressed. Therefore, any given proposal will be sent to only a few referees. The referee pool will have to be expanded to include people with expertise in fields, such as geodesy, which are unique to the VLBA. Each referee will grade the proposal and comment on what fraction of the requested time should be scheduled. The final decision will be made by a scheduling committee composed of senior NRAO staff and management, which will use the referees' comments as a guide but will have some flexibility to deviate from their judgement in special cases.

TIME ALLOCATION

Observations that include non-VLBA stations, especially ones that do not have the frequency agility and rapid communications of the VLBA, will have to be scheduled in fixed time slots as is current practice on the VLBI Networks and the VLA. However, observations that only involve the VLBA and other stations that are willing and able to change plans on short notice could be performed when most appropriate. When the weather is especially good at most sites, high frequency observations or those requiring extremely high phase stability could be done. When the weather is bad, low frequency programs could be done instead. Specific equipment failures could be mitigated by switching to projects using different frequencies, fewer baseband channels, *etc.* In the event of more general failures which incapacitate a station completely, projects that depend on the (u, v) coverage of that station could be avoided. It has been assumed since the early days of the project that the Array would support this "dynamic scheduling", as it is known in VLBA jargon. Clearly it will be difficult to manage, and it is not completely clear how it will be accomplished. However, many in the project feel that such scheduling is critical to the goal of providing high quality data for difficult observations.

Some attempt is being made now to begin what might be called "dynamic scheduling" for VLBA test measurements and VLBA-only scientific projects. This will allow the VLBA construction project to accumulate experience with this mode while it is still relatively easy.

Efficient scheduling may require staggered starts and stops across the Array as sources rise and set. This will be done (by users) for sources within individual programs but it is not clear whether it should be done for whole programs. It certainly complicates scheduling. Mauna Kea, the station likely to be affected most severely, is also the one at which single dish observing will be most valuable.

DETAILED SCHEDULING

A detailed schedule of observations must be constructed for each project. For those that are allocated fixed blocks of time, such as Global Network observations, this will continue to be the responsibility of the user. For observations scheduled dynamically, it is less clear who should make the final schedules because of the uncertainty, until very close to observe time, of the exact time slot. Clearly the user must set the observing style, and perhaps could submit a small number of alternative sidereal-time-based schedules for reasonable time slots, one of which would be used. However, it might be necessary for a staff member to make the final schedule just before the observations, based on the user's instructions. For the rest of this discussion, it will be assumed that the user is responsible for the detailed schedule.

In addition to the sequence of sources, the user must specify the observing and correlating parameters, which may change throughout the schedule. Observing parameters include frequencies, bandwidths, polarization, sample rates, and number of bits of digitization. Correlation parameters include spectral resolution, interpolation, windowing, overlapped and oversampled processing, and integration. There will be defaults and standard setups to simplify these specifications for many common observing techniques.

There are a number of items that the user is specifically *not* responsible for. These include pointing, system temperature measurement (unless it needs to be turned off), fringe finding, and tape handling. Also, the Array will provide much of the calibration information. Careful gain measurements will be made of the antennas at all the common observing frequencies. Clock drifts and coherence, station positions, and Earth rotation parameters will be monitored with frequent, perhaps daily, calibration measurements. These internal technical observations may also suffice for amplitude and bandpass calibration, although careful users may want to include compact calibration sources in their schedules. One or more appropriate sources will be monitored regularly with the VLA.

The user will be expected to transmit the detailed schedule in some established, machine readable format. This file will be used by NRAO staff to create the actual station control commands, which include detailed information about the hardware setup that does not concern the user, and is subject to change on short notice. It would be desirable to establish an international standard schedule format with which the user could send essentially the same information to all observing stations.

Software will be developed to assist the user in schedule construction. At present, VLBA observations use schedules created by the Caltech SCHED program, which has been modified to support most modes of observation including Mark II and Mark III VLBI, and single dish pointing. Files from the Haystack programs SKED or PC-SCHED, usually for Mark III observations, can be converted into SCHED input and used to generate VLBA schedules. These inputs are used by the staff to create station control files containing the latest hardware setup parameters. In the long run, NRAO may provide a VLBA analog of the VLA OBSERVE program. In any case, significant enhancements will be needed over any existing software for final VLBA use.

Schedule files in the appropriate form can be sent to NRAO electronically from the user's home institution. This service is already in operation. In fact, SCHED input files that include non-NRAO stations can be sent and will be processed by the

VLBA staff. The resulting files are copied from a VLBA computer by the staffs of other telescopes. Soon, we intend to send schedules to the non-NRAO stations automatically, via computer mail, as they become available. At least this level of service to the VLBI community will be maintained in final operation.

An alternative to the level of user involvement described above is for the user to specify only generally what is wanted and have the staff worry about all the details. This has not been common practice at the NRAO. Within the Observatory, it is widely considered desirable for the user to be involved at a reasonably detailed level with the observations so as to understand the data better. This attitude also will be apparent when the data reduction responsibilities are described.

OBSERVING

Users are not expected to be present for the observations, although their presence in the Array Operations Center will not be discouraged. It is not clear that there is anything the user could contribute to improved data quality during the observations, since the VLBA produces no real-time results. Even at the VLA, where real-time results are available, it is uncommon for users to change their programs during observing. Dynamic scheduling, furthermore, is incompatible with scheduled user visits.

It is intended that tape management not be sensitive to details of the observing schedule. Tape reversals, which take about 10 seconds, will be allowed whenever necessary, even while observing. Both at the stations and at the correlator, tape changes are accomplished with no overhead, by switching to a pre-mounted tape on another drive. Tape changes should occur only once per day on each of the two drives at a station. Each tape contains some 12 hours of data from, in general, more than one user's project. Any request to isolate particular data on a tape will throw a monkey wrench into this system. Obviously, when another large correlator becomes operational anywhere in the world, it will be necessary to record data for each on different tapes. It may be best to organize this by time, correlating alternate weeks, say, rather than by user projects.

CORRELATION

Observers are not expected to be present during correlation, either. Again, it is not clear that an observer could help significantly to improve the results, although it is recognized that there may be unusual cases where interaction with the user could enhance the scientific return from an observation. These cases will be accommodated within the limits imposed by the VLBA tape inventory and the necessity of maintaining correlator throughput.

The correlator is an integral part of a full-time instrument. Although it has an effective fourfold overcapacity, relative to the ten-station VLBA recording at its sustainable data rate, much of this margin will be dedicated to processing of extended arrays including non-VLBA stations, and to observing modes requiring multiple passes. Optimization of throughput is another major factor, and the correlator incorporates complex scheduling algorithms for this purpose. Both considerations make it necessary that VLBA staff supervise the correlation process and control all tape logistics.

The correlator staff will have good indications that correlation has succeeded from a variety of data validation processes, including on-line fringe fitting, at least of calibrators. It will not be feasible to wait for an observer to study the results before releasing the data tapes. No system of this large scale can function effectively without reliable data playback; any general reliability problems will have to be solved within the data recording system. In the case of correlator failures not noted immediately by the staff, reobserving is the only realistic recourse.

All correlator results will be archived. The archived data will become available to anyone after some pre-established period of time, as is also the policy at the VLA where that time is 18 months. Data from the archive will be distributed to users via a secondary output, in FITS format. Distribution media will include standard (but technically obsolete) 9-track computer tape, as well as some modern, high-capacity medium yet to be determined.

The distribution format will contain all information needed for any further processing (including any calibration information supplied by non-VLBA stations). It will include as well explicit information about the correlator delay and phase models, both as model parameters and as the actual model values calculated periodically during correlation. This will allow the user to remove and replace these models without having to recalculate them or know their functional details.

POST PROCESSING

The NRAO does not intend to deliver explicitly calibrated VLBA data to the observer, just as it does not do so from the VLA. However, the results distributed to users will contain all the a-priori information necessary to perform editing and calibration for the VLBA stations (and any others that are interfaced to the system sufficiently well) with minimal difficulty. Editing, calibrating, and fringe fitting will be a matter of running a sequence of AIPS programs that use this information.

Fringe fitting is considered to be a post-processing task, in contrast to some Mark III operations that now include fringe fitting as a step in correlation. This allows the user much more flexibility in the manner in which fringe fitting is done and in repeating this task with better source models, but does require computer resources. On-line fringe fitting will be available but is intended mainly for tracking station clocks and for diagnostic purposes.

NRAO will support imaging and other astronomical analysis in AIPS, although users will be free to export data to other packages. The large community of experienced VLA users should find this portion of the data reduction to be familiar. The software is the same. It is not yet clear how geodetic/astrometric data will be processed. Routines for this purpose may be incorporated into AIPS, but it is likely that interfaces to some standard geodetic programs will be provided for such analysis. A high-accuracy model calculation based on the CALC program developed at NASA's Goddard Space Flight Center will be maintained for any users who wish to adjust the a-priori geometric parameters of their observations. This same calculation is used for the correlator real-time model, so such adjustments should only be needed when improved models or parameter values become available.

Much of the post-processing software already exists. Some simple continuum observations, using data from existing correlators, have already been reduced entirely in AIPS.

It is for post-processing that users will be encouraged to come to NRAO facilities where they can use the Observatory's computing resources and can interact with the experts on the staff. However, a major goal of the AIPS project is to provide software that can be exported to the observer's home institution, so that it should not be necessary for a user to go to NRAO at any stage in a project. One of the biggest worries, in fact, is that too few users will do so, and the staff will become more isolated than is healthy. It will be especially important for inexperienced users to come to NRAO for data reduction and perhaps also for observation planning, if the most effective use is to be made of the instrument.

INTERACTION WITH OTHER TELESCOPES

It is expected that the VLBA will be used with at least some other VLBI telescopes for a significant fraction, perhaps half, of the time. A major challenge will be to make this joint operation work smoothly. There are several aspects of the problem and several possible levels of joint observing.

It should be possible for users to schedule large projects without much more effort than scheduling pure VLBA observations. This will require that the scheduling software understand other stations and that the schedule distribution scheme work smoothly. A standard schedule description format would facilitate this, and the computer mail connections that already link most observatories are likely to be central in the system. There should be no need for the paper cover sheets or backup hard copies that are now required by Network stations. The schedule distribution schemes already supported or under development by the VLBA staff are a first step in this direction.

Perhaps the most difficult problem will be the timely transmission of tapes and logging information to the correlator, so that the VLBA tape supply is not stressed. This will require that tapes be shipped very soon after recording, in contrast to the typical current practice of shipping in bulk at the end of the three-week Network sessions. Adoption of standard formats would allow logging information from all stations to be read into the VLBA database. Computer mail may again be central to the distribution of logging information.

There are three basic levels of cooperation with the VLBA. A few telescopes may have sufficient flexibility, combined with good communications and appropriate policies, that they could participate in almost any VLBA observation, even those scheduled dynamically. No existing station is obviously in this category, but it is likely that some new telescopes will be built with fully VLBA-compatible capabilities or that some older facilities will be so upgraded. A large number of telescopes, including all current Network stations, will likely fall into the second category. These are telescopes that easily and routinely participate in Network style observations. They have all the required equipment and participate regularly in VLBI so that special arrangements are not needed. However, they are not in the first group because they require advance scheduling and cannot, for technical or policy reasons, switch programs quickly. Any VLBI spacecraft will probably fall into this group. Finally there are telescopes, needed for special and unique observations, that normally are not involved in VLBI at all. Such telescopes might require borrowed recording equipment and time standards, and the interfaces to the VLBA will be primitive. The VLBA budget makes no provisions for such situations.

Most global observations will involve telescopes of the second type listed above. Specific time slots will have to be allocated well in advance for such observations, perhaps by a Global VLBI Network. A potential intermediate scheme between the first and second categories would involve a very limited form of dynamic scheduling, perhaps based on preplanned backup programs and probably restricted to a single frequency band.

The VLBA can serve as a focus for detailed schedule generation and distribution, for correlation, and for monitoring the performance of the global array. These observations will be considerably more trouble than pure VLBA observations, but they provide tremendous additional capabilities in both (u, v) coverage and especially in sensitivity, and will contribute enormously to the overall VLBI effort in the VLBA era.

CONCLUSION

The plans outlined in this document represent operational goals. At present they appear to be feasible, at least in the long run, and many are nearing implementation. However, operation of the VLBA is still in a rather embryonic state, and additional experience with this new instrument will be necessary before firm policies can be formulated.