Project title: e-VLBI

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Users or Customers: Astronomy community.

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Science case

VLBI provides the highest resolution achievable in radio astronomy. However, its dependence on tape recoding systems and delayed correlation make it labour intensive and often limit its potential uses. Recent progress in networks has started to make it possible to connect VLBI antennas and correlators in real-time, called e-VLBI. Limited tests of e-VLBI have already been done in the USA and Europe.

Recently (November 2003 and April 2004) initial e-VLBI tests have been undertaken in Australia as a collaboration between the ATNF, the Swinburne University of Technology, and the University of Tasmania. These tests have been successful and demonstrated the real-time correlation of extremely small volumes of data, transported over the existing networks between Parkes, the ATCA, Mopra, and Ceduna. These tests prove that much larger scale e-VLBI experiments, with significant scientific applications, will be feasible once the network speed has been improved.

In Australia, the regional network of AARNET3 makes it feasible for the first time to connect all ATNF antennas at high data rates. At least 1 Gb/s will be implemented this year and within a few years multiple 10 Gb/s channels will be available.

In the same time frame, the ATNF is building the new wideband correlator facility at Narrabri. With some extra effort in the design phase, this correlator could handle VLBI correlations in real time. This facility will be available in about 3 year's time.

Thus the convergence of these two developments provides a unique opportunity to develop an e-VLBI network in Australia. The multiple 10 Gb/s rates possible will surpass the capability of any planned VLBI network in the world. e-MERLIN is the only other instrument planning such high data rates but with shorter baselines and less sensitivity.

The unparalleled sensitivity of such a system will permit the exploration of a new parameter space of high sensitivity and high resolution VLBI. The potential for new and exciting research is very high. A more detailed science case for astronomy with e-VLBI is being developed.

Description

Deliverable

What will be produced?

e-VLBI will deliver real-time VLBI correlation at high (Gb/s) rates. There are a few distinct aims in this project:

1. Deliver ~1Gb/s rates within about 1 year. Delayed correlation will be done with the Swinburne supercomputer.
2. Real-time correlation at 256 Mb/s rates at Epping with the LBA correlator.
3. Real-time correlation of 2 x 8 Gb/s data streams from each antenna into the ATCA broadband correlator in ~3 years.

User requirements

Brief quantitative statement of what is required

Primary requirements are:

- **High sensitivity** achieved by high bandwidth, which will be enabled by the fast network connections.
- **Real-time correlation** to streamline and integrate operations within ATNF. This will also enable fast results and change the nature of VLBI observations.

Concept

Brief statement of how this will be achieved

To achieve these results the project has distinct phases:

A. **2004: Demonstration phase** at 256 or 512 Mb/s. This will connect ATCA and Mopra to Parkes via the new AARNET3 network and correlate "near real-time" using the Swinburne 32-node computer cluster. Primarily a demonstration and publicity exercise.

B. **2005: High data rates**, using existing ATNF telescope equipment with minor modifications/extensions. 256 Mb/s are available now. 512 Mb/s will be available with small effort. 1Gb/s may be available by duplicating equipment. Correlation at these rates will be done by the Swinburne supercomputer. The data may need to be stored on disk at Swinburne as correlation may not possible real-time.

C. **2005: Real-time correlation,** at 128 or 256 Mb/s using the existing correlator. This requires some developments at the LBA correlator.

D. **2007: Real-time correlation and high data rates,** at 2 x 8 Gb/s using the new broadband correlator at the ATCA.

E. **2004-7: Connect non-ATNF antennas,** both in Australia and overseas. This will take place in parallel with many of the other phases.

Scope

What is included; what is ***excluded***

The project includes:

- Development of data recording and buffering technologies (under way at Swinburne)

- Development of software correlator by Swinburne, already under way.
- Developments to connect to the LBA correlator.
- Connections to the broadband correlator at Narrabri.
- Extensions to enable the ATCA correlator for e-VLBI.

The project does not include at present:

- Development of wideband Receivers and Data-Acquisition-Systems (DAS). These will be developed for the ATCA wideband system independent of e-VLBI and will need to be at least duplicated at other antennas.
- Network connections. These will be provided by AARNET3 and CSIRO ITS.
- Broadbanding and connections to non-ATNF antennas. These will need to happen as independent developments.

Resource estimate

Separate cost and labour estimates are done for each of the phases of the project (A-E) but each phase will use equipment and products of the previous phase. Some phases could be developed in parallel e.g. B&C.

Cost

Preliminary cost estimate

A. For the demonstration phase in 2004, current systems will be used to acquire the data onto disks and transfer it over the network to Parkes. Similar results already obtained with current test disk systems. Main extra costs: Interface cards to network **~$20k** for 4 connections.

B. Costs outlined for different sections of this work;

- Interface cards to network at Swinburne, 3 connections **~$15k.** The telescopes already have interface cards from phase A.
- Data disks will be needed at Swinburne. **$??**
- PCs at the telescopes, **$6k**
- PCEVN cards for telescopes, **$10k**
- For 512 Mb/s, components needed for DAS mods. **~$10k**
- For 1 Gb/s, some equipment may need duplication, **~$10k**

C. A number of tasks are needed at the LBA correlator:

- Network interfaces, at least 3 for ATNF antennas, **$15k**
- Delay units to be developed, e.g. disks **$15k**
- (If other Oz antennas could be connected ***,+$30***)

D. This phase is part of the broadband ATCA correlator. Extra costs:

- Network interfaces at 10 Gb/s, at least 6 for ATNF, **$50k**
- Extra buffering for VLBI delays, other VLBI h/w **$100k**
- Wideband Rx will happen at ATCA and Mopra but need to be funded additionally at Parkes at **$??**
- Samplers and DAS will be built for the ATCA. For Parkes and Mopra the extra costs will be: *$20k per pair of fast samplers + 30k per polyphase filter* i.e. **$50k each for Parkes and Mopra**.

E. Connection of other antennas would involve duplications of costs above and will depend on network connections available. Minimum for each antenna:
   - Network connections $10k/antenna
   - Correlator delays etc already built in for 6 antennas.
   - Fast samplers (CA design?) at $20k/anntenna
   - DAS (polyphase filters?) at $30k/antenna.
   - New computers, interfaces etc ~$10k
   - Wide band receivers $??
   - ***Total: ~$70k/antenna***

Labour

Preliminary labour estimate

A. Small developments to connect to new network. **~0.5 FTE** overall.
B. Labour for different sections:
   - Correlator software development at Swinburne, **~1 FTE**.
   - Network connections software development **~0.3 FTE**
   - DAS developments for 512 Mb/s & 1 Gb/s **~0.3 FTE**

C. Labour for different sections:
   - Delay unit development **0.5 FTE**
   - Correlator software mods **0.5 FTE**

D. Main labour components for design and building of correlator are part of the ATCA wideband upgrade. Additional labour for e-VLBI:
   - Design for VLBI delays/rates **~0.5 FTE**
   - Extra software modes **~0.5 FTE**

E. Up to 6 stations already built into correlator design. Minimal extra effort, apart from designing for the longer baselines.

Summary: Rough cost for all phases at ~$500k & ~5 FTE.

Risk assessment

Outline the main risks

A. Little risk from the demonstration phase, as most components are already in place for a basic demonstration.
B. The network and its characteristics have not been decided at present. Thus:
   - Connections to network may require more development.
   - The rate may also be limited by network configuration and traffic.
   - Limits on how much observing the software correlator could handle.

C. Feasibility and costs of converting the LBA correlator to real-time operations have not been studied in detail. If the cost and effort required prove excessive it may be prudent to wait for the ATCA wideband correlator before real-time correlation commences.
D. The final stage is heavily dependent on the ATCA broadband correlator. The e-VLBI developments should not unduly delay the ATCA correlator.
E. Funding of broadband upgrades and network connections for non-ATNF antennas is not clear at present. These must be developed to achieve the full potential of the network. Other technical and political developments may impact on these.

General risks:

- Loss of functionality from present LBA array e.g. fewer telescopes connected may result in an array not suited to imaging.
- Compatibility with other VLBI networks. May have to develop/retain some disk recording capacity.

Relevance

Brief statement of benefits to the ATNF

Strategic benefit

e-VLBI developments leverage on the technical developments within ATNF such the ATCA wideband correlator. They also fit well in demonstrating key SKA capabilities such as fast networking and real-time correlation over long baselines. The e-VLBI capability can also be used to demonstrate the relative radio-quietness of SKA sites and RFI mitigation strategies.
The early parts of the e-VLBI project rely heavily on software correlator developments at Swinburne. These are part of the SKA development effort and are supported by MNRF funding.
Strategically, e-VLBI leverages on network developments such AARNET3. Connectivity is also becoming available to overseas (USA, Japan) and collaborative efforts are already underway.
These obvious strategic benefits have attracted Steering Committee endorsement.

Scientific benefit

The main scientific benefit will come from the increased sensitivity of the VLBI array. The data rates will increase by 128 times and hence the sensitivity will increase by more than 10 times. Coupled with the parallel development of wide-field VLBI imaging techniques, e-VLBI can achieve high sensitivity, high resolution and wide-field at the same time. This will enable VLBI detection of a new population of weak sources, opening up a new parameter space. The proposed e-VLBI array will be the most sensitive VLBI array proposed to date.
A more detailed science case is being developed.

Technical benefit

e-VLBI will demonstrate key technologies for the SKA and leverage of technological developments in ATNF, Swinburne and fast networks such as AARNET3. The increase in VLBI sensitivity in this manner is equivalent to increasing the diameter of all antennas in the array by a factor of 3, which will cost more than $2B. Thus, the bandwidth increases enabled by the fast networks are a very cost efficient means to increased sensitivity.
Details of the benefits to VLBI from the fast network links are given in Attachments B & C of the ITS business case for the networking project.