Electronic Transmission and Computation of Very Long Baseline Interferometry and Its Application to Next Generation Radio Telescopes

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Abstract

Australia is contributing to the next generation radio telescope, the Square Kilometre Array (SKA), which will have a collecting area of one million square metres. The SKA will be a digital radio telescope that will rely on high-speed data communications for routine global electronic transmission of VLBI data and some traditional analog stages will be replaced by software-defined blocks on fast processors.

1. Introduction

The Square Kilometre Array (SKA) is a next-generation radio telescope planned for operation around 2015. As the name implies, it will encompass a square kilometre of collecting area. It represents a large step into new parameter space for radio astronomy, with 100x greater sensitivity than existing instruments. However, it also poses significant engineering challenges, with the science requirements dictating that data volumes far in excess of any present applications be collected, transmitted over thousands of kilometres and processed in real time. This combination of modern networking and Very Long Baseline Interferometry (VLBI) is known as eVLBI.

This work aims to begin to address some of these challenges, while simultaneously making a contribution to an active Australian scientific instrument, the Long Baseline Array (LBA). Recently the LBA has been upgraded to make use of disk-based recorders which allow increased bandwidth and flexibility, but to date disks have been transported after the observing session to a central location for correlation, which has run many times slower than real-time. By developing the networking and correlating techniques necessary to demonstrate operation of the LBA in real-time, a substantial demonstration of SKA technologies can be made at the same time as improving the responsiveness and effectiveness of the existing LBA.

2. The Model

For Australia and Western Australia to remain competitive in the bid for the SKA telescope, it is vital that WA support CSIRO Australia Telescope National Facility (ATNF) in establishing a record of accomplishment in technically supporting, and contributing to the computational and networking challenges that will be generated by this giant radio telescope. In particular, WA must institute the necessary infrastructure to support computer hardware and software to prove that it is capable of supporting a high resolution software radio telescope.

The first aspect of this project involves the transmission of radio astronomy data from widely separated antennas to a centralised processing area. The first steps towards this goal were taken in September 2005, when data transmission was tested between the ATNF site in Marsfield, via GrangeNet to Melbourne and on to Perth (where the data will be correlated) via a Centre for Networking Technologies for the Information Economy (CeNTIE) link. During this test, which used a 1 Gbps link, data rates in excess of 800 Mbps were sustained.

However, before actual telescope data can be transferred in real time, the participating telescopes must be connected to the Sydney-UWA link. Fibre backbones operated by organizations including Australia's Academic and REsearch Network (AARNET) and GrangeNet exist along Australia's east coast, and discussions with these organizations have shown that a willingness exists to demonstrate their high-speed potential. The last remaining connections are the 'last mile' fibre tails to the actual radio telescope sites. Recently, CSIRO announced that funding had been allocated to connect the Parkes, Narrabri and Mopra sites, with work commencing immediately and expected to be complete by the end of 2005. At present, the only remaining obstacle is the routing of the data from the AARNET fibre to the GrangeNet fibre, which may require either the purchase of capacity on an additional link (to allow routing via Marsfield), or the installation of a switch at the University of Technology, Sydney, which both networks currently pass through. Complete data transfer tests can thus be undertaken in early 2006, paving the way for 'live' real-time correlation at the UWA facilities in Perth.

The second aspect of the project involves investigating novel correlator architectures, which are compatible with the disk-based recorders currently available for the LBA (which are capable of recording up to 512 Mbps in a standard mode, and will soon be able to record up to 1 Gbps in special modes). This research has focussed on software correlators, which implement the correlation algorithm in software on generic commodity machines using optimised vector processing libraries.

A version of this software correlator is available for use on a commodity cluster at Swinburne, but due to limited connectivity to the Swinburne site this is not a feasible option for real-time correlation in the near future. We have therefore focussed on developing the software correlator on the Cray XD-1 architecture which is available on the UWA site, and a version of the correlator has been successfully tested on the XD-1. However, as the XD-1 contains only 12 processors (c.f. >300 on the Swinburne cluster), it is necessary to investigate acceleration options. We have investigated the use of Field Programmable Gate Arrays (FPGAs) and Programmable Graphics Processing Units (PGPUs) as acceleration components, both of which can be tightly integrated into the Cray machine.

FPGAs have received increasing attention in the radioastronomy community recently, with several wholly FPGA based correlators being built. The advantage of FPGAs lies in their fast parallel processing capability, combined with reconfigurability for multiple applications. PGPUs, on the other hand, have not yet been applied to radioastronomy correlators. Despite having a very different architecture to FPGAs (being more similar to a standard CPU), they share the ability to process multiple streams of data in parallel due to multiple internal pipelines, developed for intensive rendering algorithms. In both cases, the hardware power increase has been exceeding Moore's law, making both architectures increasingly attractive for implementing computationally intensive portions of the correlation algorithm.

Through collaboration with Cray, FPGA binaries which implement a large fraction of the correlation algorithm have been developed and are currently being tested and integrated with the software correlator. Initial simulations suggest that a speedup in excess of an order of magnitude will be obtainable for that portion of the algorithm. With further optimisation, real-time operation on the XD-1 using FPGAs is almost certain to be achieved in 2006.

Development on the PGPUs is less advanced, but should proceed rapidly due to a more familiar architecture and easier integration into the software correlator. Additionally, multidimensional FFT libraries already exist for PGPU architectures, which should be adaptable to the single dimension FFT applicable to software correlation. The approach for the PGPU mirrors the FPGA functionality and fit in with the existing correlator code. This will allow for initial benchmarking between the two architectures, which is currently scheduled for February 2006.

With the groundwork now laid, work over the next 3-4 months will concentrate on achieving the milestone of combining real-time data transmission with real-time processing - "real" eVLBI, the first such experiment in Australia. The next LBA observing session is slated for March 2006, and the first real-time test is planned to occur during this session.

3. Conclusions

Novel correlation methods and high-speed data transfer over vast distances form an important component to the bridge that must be built between present correlators and the equipment required by the SKA. We remain on track to demonstrate real-time eVLBI early in 2006, which both validates the concepts required by the SKA, and markedly improves the versatility and effectiveness of Australia's current VLBI instrument, the LBA.