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The Contribution of ESLEA to the Development of e-VLBI

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e-VLBI - the use of the Internet in real time VLBI high resolution observations in radio astronomy - has become a routinely available technique in this last year. ESLEA has contributed significantly to its development, by improving our understanding of data transmission networks, the limitations of transport protocols and end hosts, and communication of this knowledge to radio astronomers in Europe. A series of tests, organised by JIVE in the Netherlands and ESLEA has gradually led to open call science runs, now considered as a regular part of European VLBI Operations. A major upgrade project - EXPReS - is now underway to equip more European observatories with e-VLBI capability. This paper outlines the work done in ESLEA on e-VLBI and illustrates its success by showing recently obtained astronomical results.

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[1] Speaker

1. Introduction

The radio astronomy technique known as VLBI (Very Long Baseline Interferometry) achieves the highest angular resolution in astronomy by making use of telescopes situated all over the world. The technique traditionally relies on the ability to record the signals from the receivers in the telescopes on magnetic media. The first systems in regular use in the 1970s, e.g. the Mk1, used computer tape. The Mk2 system used helical scan video recorders, starting off with Ampex 2" tape systems [1]. These systems had limited bandwidth, and so the 1980s saw the development of the Mk3 using wideband longitudinal instrumentation recorders able to record at 56 Mbps. This system was later developed into the Mk4 in the 1990s- able to record in principle at rates up to 1024 Mbps, though somewhat unreliable at rates higher than 500 Mbps. More recently the advent of high capacity computer disks (the Mk5 system) now means that reliable recording at 1024 Mbps can be performed. (NB data rates inVLBI systems are in powers of 2 due to technical constraints.)

The recorded data are shipped to a central processor, where the tapes or disks are played back together, and the signals cross-correlated (in case of European VLBI this correlator is at JIVE in Dwingeloo, The Netherlands). The angular structure of radio sources can be obtained by Fourier inversion of the correlated data taken over a number of baselines. The number of Fourier components is effectively increased (and hence improved imaging fidelity) by means of Earth rotation, where the projected baseline length varies with time, tracing out part of an ellipse over ~12 hours [2], and the angular resolution is inversely proportional to the maximum length of the baseline, so trans-world arrays produce images showing the finest detail.

2. e-VLBI

e-VLBI, where the data are transferred to the correlator in real time via the Internet has been developed recently. Initial tests were at relatively low data rates, up to 32 Mbps, using production academic network packet switched connections from telescopes to JIVE, but nevertheless interesting results were obtained [3]. e-VLBI has a number of advantages, in particular the ability to check that everything is working immediately rather than the wait of several weeks or even months for tapes to be shipped and correlated. This can result in a significant increase in reliability for VLBI operations. In addition, the technique lends itself to rapid reaction observations – where subsequent observations on rapidly varying objects can be decided upon within hours rather than weeks after initial measurements are made.

The signal to noise ratio for a wideband continuum source is proportional to $\sqrt{B\tau}$, where B is the bandwidth and τ the total time on source, so bandwidth is as important as time. There is an obvious need for high data rates. Note that typically a data rate of 512 Mbps corresponds to a bandwidth of 128MHz, using 2 bit digitization (possible due to the characteristics of random signals) and a factor of 2 for the Nyquist rate. Very high data rates are in principle possible using fibre-optic technology, well in excess of that accessible in recording techniques, so e-VLBI could eventually give a new level of sensitivity in high resolution astronomy. However the data needs to be continuously streamed, and usage of standard production networks is now such that congestion is likely to occur at rates of a few hundred Mbps. Protocols such as TCP will drop data rates dramatically even with only one packet lost [4], so though the data loss may be negligible the drop in data rate will seriously degrade the sensitivity of the array, with the effects made worse by the long recovery time of long links running at high rates. The answer is in the use of switched light paths, where bandwidth is more easily guaranteed.

3. ESLEA

The ESLEA project has greatly helped the development of e-VLBI at Jodrell Bank Observatory by providing resources: the provision of two UKLight lightpaths to Amsterdam from Jodrell Bank Observatory (at 1 and 0.63 Gbps), a post-doctoral research assistant (Matt Strong) and funds for computing resource. Our objectives were to demonstrate the advantages of data transport over UKLight compared to that available on production networks, formulate methodologies for optimum use of switched light paths and help bring e-VLBI to the user within the European VLBI context. These aims were achieved by making comparison tests to JIVE on UKLight and production links (see figure 1), developing a UDP based data transfer protocol specifically for e-VLBI [5], optimising TCP parameters for Mk5 data transfer and upgrading Mk5 hardware [6]. In addition tests to USA have been made [7]. Development of e-VLBI has also been helped by investigations of TCP performance [5] and by measurements of correlator performance in the face of high packet loss [8].

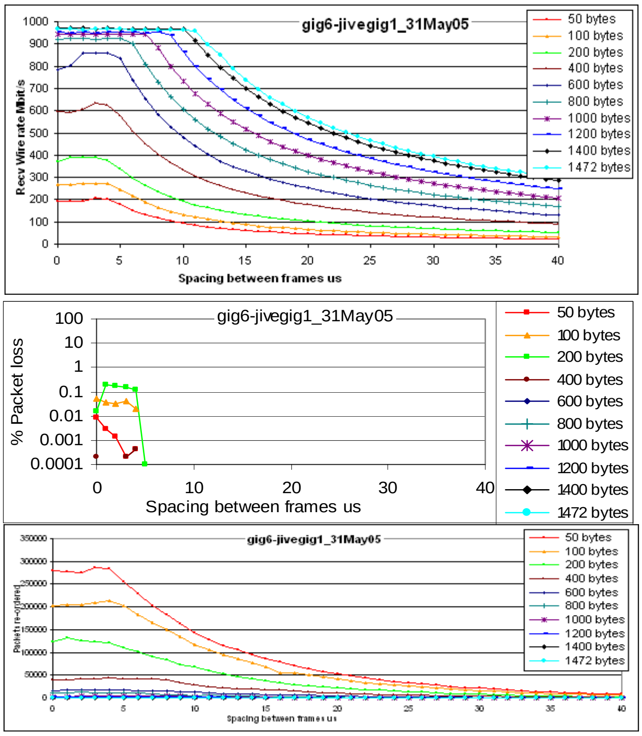

Figure 1. This shows tests on the production academic network between high performance server class machines situated in Manchester and JIVE in the Netherlands. The upper plot shows throughput vs demanded interpacket spacing for a variety of packet sizes. Small packets require more computing and network resource, and this results in a few lost packets (middle plot). The lower plot however shows that significant reordering has taken place. It is significant that tests on UKLight showed no re-ordering, see plot in [6].

Particular milestones in e-VLBI relevant to ESLEA have been:

- The setting up of regular tests with e-VLBI run every ~6 weeks since early 2005 [9],
- A demonstration at the GEANT2 launch in Luxembourg showing 3 way flows up to 800 Mbps across GEANT in June 2005.
- Trans-Atlantic data transfer from Onsala, JBO and Westerbork to the Haystack correlator in Massachussets, USA, during iGRID 2006 and SC2006, producing real time e-VLBI fringes at 512 Mbps. These demonstrations used UKLight connections across the Atlantic and were initiated by JBO staff.
- The first successful open call e-VLBI real time European VLBI session in April 2006.
- The first scientific real time e-VLBI results published in 2007 [10,11] (figure 2), and real time eVLBI science observing sessions becoming a regular part of European VLBI operations in 2007.

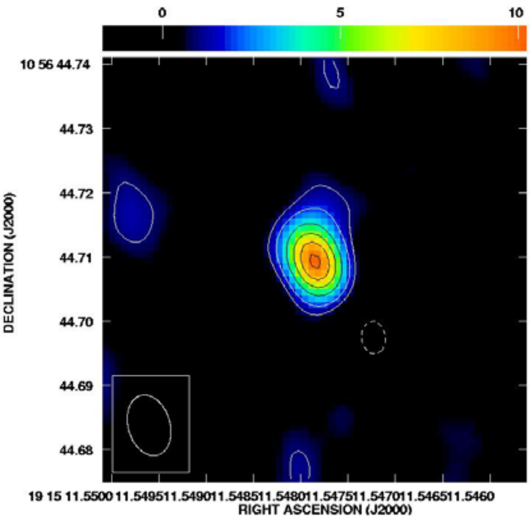

Figure 2. Microquasar GRS1915+105 (11 kpc) on 21 April 2006 at 5 Ghz using 6 EVN telescopes during a weak flare [10]. This object has jets of material which move away from an accretion disk surrounding a central black hole at velocities close to that of light. The jets were quiescent in these observations.

4. Conclusion

In summary, the ESLEA e-VLBI project has been very successful, achieving all its original aims, and even leading to further developments. We are now able to perform routine real time eVLBI measurements at data rates of 256 Mbps, and 512 Mbps tests are underway. An illustration of this was performed recently when the first rapid response experiment was undertaken (investigators A. Rushton and R. Spencer). Here a 6 telescope real time observation was run on 29th Jan 2007, the results were analysed in double quick time, selecting sources for follow up observations on 1st Feb. This kind of operation would be impossible for conventional VLBI. The experiment worked well technically – we successfully observed 16 sources (weak microquasars), but all were <0.5 mJy – too weak to observe in the follow up run – indicating a perverse universe, however the feasibility of the technique was clearly demonstrated. Our work on e-VLBI is now concentrating on the EXPReS[1] project where with the objective is to create a distributed, large-scale astronomical instrument of continental and inter-continental dimensions.

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