eVLBI: Networks Bringing Radio Telescopes Together

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INTRODUCTION

The angular resolution, or detail, that a telescope can achieve depends on the wavelength of the light and the diameter of the telescope. Given radio waves are up to a million times longer than optical light, radio telescopes would need diameters of many kilometers to have the same resolution as ground based optical telescopes. To overcome this limitation, interferometry is used where the signal from multiple, smaller, telescopes is combined and processed in a supercomputer to synthesize a telescope the size of the largest separation between the telescopes. Connected element interferometry is where the individual telescopes can be connected to the processing backend via waveguides, coax cables, optical fiber etc.

Very Long Baseline Interferometry (VLBI) is a version of interferometry at radio wavelengths where the separation between to telescopes is too long to directly connect. Distances of 1000's of kilometers or more are typically used, experiments using space based telescopes have also been run synthesizing a telescope 3 times the size of the Earth. Because the separation between the telescopes is so large, VLBI has been forced to digitize and record the collected radio signal at the telescope onto some sort of recording medium (historically specialized magnetic tape, for the last few years standard computer hard disk drives). While this works very well there is a significant time lag (generally months) while the recorded data is shipped to a central location and processed on a super computer.

VLBI requires high data rates as radio sources are very weak and wide bandwidths are sampled. Sustained data rates of up to 1 Gbps for many days are currently used for each telescope. Next generation systems are currently being developed with sustained data rates of 4-16 Gbps.

eVLBI is the next stage in VLBI evolution. With the advent of broadband networking technology (1 Gbps and greater) it has become feasible to dispense with recording data and the digitized data is transmitted in realtime over commodity networks. The data is then fed into a Beowulf style cluster of computers to combine and process the data in realtime. This has the advantage of immediately knowing if the telescopes are functioning, allowing the data to be available to astronomers as soon as the observing has finished and eliminating the cost of shipping disks. Long-term eVLBI should allow higher data rate rates (which means higher sensitivity) than disk-based recording.

INTERNATIONAL EVLBI

Internationally 25 radio telescopes, with sizes from 15 to 300m, take part in regular eVLBI. See Figure 1 for an overview of the location of these telescopes and the network links between them. Data rates of up to 512 Mbps per telescope are used between continents and up to 1 Gbps within Europe and 1 Gbps within Australia. In Japan a regular monitoring experiment between two telescopes is run with a data rate of 8 Gbps. Development of international eVLBI has been challenging due to the fact there is neither a standard VLBI data format nor a single VLBI acquisition system. Never the less the various groups across the world have worked closely with each other and written translation software which converts one data format to another in realtime before transferring to the central processing site. Connecting the telescopes to the central processor is still problematic. The connection from each telescope typically spans multiple networks and each segment has to be individually negotiated. As all the data comes to a central site, the incoming data volume can be very large.

AUSTRALIAN EVLBI

ATNF works closely with AARNet to deliver eVLBI. In Australia, there are 6 radio telescopes, which take part in regular VLBI experiments, of these 4 are connected by fast networks and take part in eVLBI experiments within Australia and internationally. ATNF runs 3 telescopes in NSW (Parkes, Mopra and ATCA), which are interconnected by 1 Gbps point-to-point networks. This allows eVLBI at up to 1 Gbps between the 3 telescopes. The University of Tasmania runs a telescope near Hobart. This telescope is connected to the University on a 1 Gbps network, but the bandwidth across the Bass Strait limits eVLBI to a maximum of 128 Mbps. We have also demonstrated eVLBI at 1 Gbps from each telescope, sending the data to a supercomputer at Curtin University of Technology in Perth. This utilized the standard AARNet3 backbone using 3.2 Gbps of capacity east to west.

eVLBI Technology

Within the ATNF networks, TCP is generally used as the preferred transport protocol. The links are uncongested and close to loss free. Although the round trip times are moderately long, the TCP delay-bandwidth problem is easily overcome. However for any data transfers over the routed networks, TCP has not been able to deliver high data rates, even though the networks are not congested. The firewalls and routers over the links drop enough packets that TCP cannot ramp up to maximum speed. For this reason UDP has been used for most international eVLBI experiments and on transfers across the AARNet3 backbone. Although high-speed UDP transfers are potentially damaging to other users of shared networks, this has not caused a problem and a close eye is kept on the data transfers and data rates dropped if necessary.

The underlying networks are an ad-hoc mixture of routed networks, dedicated lightpaths and shared layer2 links. While a single type of network access would be advantageous, it would be unrealistic given the vast number of network paths that must be bought together. As long as the underlying connections are not congested there is minimal difference in the performance between the various approaches, although routed networks typically show a low-level packet loss of 0.1-1%, which is tolerable. The biggest problem with routed networks has been making sure the route goes over the desired path with the maximum bandwidth, not lowest RTT or least number of hops etc.

eVLBI Future

The main developments for eVLBI in the future is connecting more telescopes and increasing the bandwidth available to each telescope to 10+ Gbps. To process such large amounts of data distributed computing will become increasingly important. Longer term (2020) the international astronomy community is focused on the Square Kilometre Array (SKA), which will be built in either Australia or South Africa. This is a radio interferometer with a collecting area of roughly one square kilometre, distributed across 3000km in ~100 sites. Rates of 100 Gbps from each site will need to be brought to a single central data processor for realtime processing.

eVLBI Demo

After the talk we will demonstrate a live eVLBI experiment between Australian telescopes.

Figure 1: eVLBI enabled telescopes across the globe.