Lessons from EXPReS and the future of e-VLBI

Paul Boven

Image by Paul Boven (boven@jive.nl). Satellite image: Blue Marble Next Generation, courtesy of NASA Visible Earth (visibleearth.nasa.gov).
What is JIVE?

Operate the EVN correlator and support astronomers doing VLBI.

A collaboration of the major radio-astronomical research facilities in Europe, China and South Africa

A 3 year program to create a distributed astronomical instrument of inter-continental dimensions using e-VLBI, connecting up to 16 radio telescopes
Very Long Baseline Interferometry

- Create a huge radio telescope by using telescopes in different locations around the world at the same time.

- Resolution depends on distance between dishes, milli-arc second level.

- Sensitivity on dish area, time and bandwidth.

- Requires atomic clocks stability for timing.

- Processed in a special purpose super-computer: Correlator, 16x 1024Mb/s.
Very Long Baseline Interferometry

• Initially (1990) we used large single-reel tapes

• Then came harddisk-packs

• And now: e-VLBI
Why e-VLBI

• Quick turn-around
• Rapid response
• Check data as it comes in, not weeks later (You can’t redo just 1 telescope)
• More bandwidth
• Logistics (disks delayed/deleted/damaged/destroyed)
• ‘Greener’ than hauling petabytes of disk around

Example: Cyg X-3
• Star + black hole
• Flares irregularly
• Timescale: days
• Left: 2 weeks late
• May: Observed flare with e-VLBI
Networking challenges

e-VLBI is:

- High Bandwidth: > 1 Gb/s
  (currently: 1024Mb/s data)
- Long Distance: Worldwide
- Real-time
- Long duration: 12 - 24 hours
- Not full-time
- But a little packet loss is OK
TCP behaviour

At large RTT, TCP cannot recover from packet loss

TCP-BIC stacks

Shanghai to JIVE

622Mb/s lightpath to HK

Apx. 25 packets lost in 5 minutes

Achieved only 33Mb/s
Tcp Research

- Mirror port (span)
- eVLBI: RTT up to 354ms
- Window Size
- SACK-bugs
- Tuning defeats fairness

Conclusion:
- UDP
- Private connections (LP, VLAN, DF etc.)
### Lightpaths

- Dedicated point-to-point circuit
- Based on SDH/Sonet timeslots (NOT a lambda)
- Stitched together at cross-connects
- Guaranteed bandwidth
- But also: a string of SPFs.

#### JIVE Lightpath status

<table>
<thead>
<tr>
<th>Lightpath</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>C17 (WSRT)</td>
<td></td>
</tr>
<tr>
<td>C10 (Sheshan)</td>
<td></td>
</tr>
<tr>
<td>C9 (ATCA)</td>
<td></td>
</tr>
<tr>
<td>C8 (Medicina)</td>
<td></td>
</tr>
<tr>
<td>C7 (Cambridge)</td>
<td></td>
</tr>
<tr>
<td>C5 (Parkes)</td>
<td></td>
</tr>
<tr>
<td>C4 (Jodrell Bank)</td>
<td></td>
</tr>
<tr>
<td>C1 (Torun)</td>
<td></td>
</tr>
</tbody>
</table>

---

**e-VLBI**
Lightpaths

- Especially the longer lightpaths have many outages
- NRENs usually very good about coordinating maint.
- e-VLBI is becoming a ‘target of opportunity’ instrument, planned and unplanned observations
The 1Gb/s speedbump

• VLBI (tape based) comes in fixed speeds, power of 2: 128Mb/s, 256Mb/s, 512Mb/s - and 1024Mb/s

• 1024Mb/s > 1Gb/s! (with headers it’s more like 1030)

• Dropping packets works but is sub-optimal

• Dropping ‘tracks’ to <1Gb/s: Takes a LOT of CPU work

• Lightpaths come in ‘quanta’ of 150Mb/s, but Ethernet doesn’t. 10G is expensive - L2SS?
## Network Overview

<table>
<thead>
<tr>
<th>Telescope</th>
<th>CC</th>
<th>Bandwidth</th>
<th>RTT (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheshan</td>
<td>CN</td>
<td>622M LP (Canarie) / 512M R (TEIN3)</td>
<td>354 / 180</td>
</tr>
<tr>
<td>ATNF</td>
<td>AU</td>
<td>1G LP</td>
<td>343</td>
</tr>
<tr>
<td>Kashima</td>
<td>JP</td>
<td>512M R</td>
<td>288</td>
</tr>
<tr>
<td>Arecibo</td>
<td>PR</td>
<td>512M VLAN (ToD restrictions)</td>
<td>154</td>
</tr>
<tr>
<td>TIGO</td>
<td>CL</td>
<td>95M R (Must be reserved)</td>
<td>150</td>
</tr>
<tr>
<td>Westford</td>
<td>US</td>
<td>512M R</td>
<td>92</td>
</tr>
<tr>
<td>Yebes</td>
<td>ES</td>
<td>1G R</td>
<td>42,1</td>
</tr>
<tr>
<td>Torun</td>
<td>PL</td>
<td>1G LP / 10G R</td>
<td>34,9</td>
</tr>
<tr>
<td>Onsala</td>
<td>SE</td>
<td>1.5G VLAN / 5G R</td>
<td>34,2</td>
</tr>
<tr>
<td>Metsahovi</td>
<td>FI</td>
<td>10G R</td>
<td>32,7</td>
</tr>
<tr>
<td>Medicina</td>
<td>IT</td>
<td>1G LP</td>
<td>29,7</td>
</tr>
<tr>
<td>Jodrell Bank (MERLIN)</td>
<td>UK</td>
<td>2x 1G LP</td>
<td>18,6</td>
</tr>
<tr>
<td>Effelsberg</td>
<td>DE</td>
<td>10G VLAN (shared with LOFAR)</td>
<td>13,5</td>
</tr>
<tr>
<td>WSRT</td>
<td>NL</td>
<td>2x 1G CWDM (DF)</td>
<td>0,57</td>
</tr>
</tbody>
</table>
Telescopes in the EVN and other e-VLBI telescopes
1. Arecibo switches to 256Mb/s after 12UTC. Disappears 40 minutes early due to IRNC outage.
2. Source rises at Sheshan (CN).
3. Effelsberg VLAN connection fails, fall-back to 512Mb/s.
4. UK network connections disappear.
5. Packet loss on SH link keeps traffic down to <500Mb/s (instead of 512Mb/s).
6. Effelsberg link works again, switching back to VLAN path, 1024Mb/s.
7. New EVN e-VLBI speed record: 8.16G.
Results from EXPReS

- EXPReS ran from March 2006 to September 2009
- e-VLBI developed into a working application
- TCP not suitable on high BDP paths
- Needs dedicated or overprovisioned networks
- Challenge to reliably send data at highest possible speed
  - Trunks, Channel dropping, MerlinCast, Elliptical Robin
- e-VLBI increases robustness
  - Real-time continuous data checks
- Enables interesting new science
  - Target-of-Opportunity e-VLBI, Transients
- Especially on long-distance paths,
  Network reliability is an issue
- Very successful collaboration of networkers and astronomers

e-VLBI follow-up of supernova SN2007gr showing relativistic expansion - Paragi et al 2009, accepted for publ. by Nature
New EXplorations Pushing Robust e-VLBI Services

- New EC FP7 proposal, just submitted
- 14 partners: Astronomical Institutes and NRENs
- Not a repeat of EXPReS, but new research and goals:
• Bandwidth-on-Demand instead of static lightpaths:
  • More efficient use of networking resources
  • Flexibility: different telescopes, correlators
  • Interface to reserve telescope, network and correlator capacity
  • Higher speeds for increased sensitivity: 4Gb/s, 10Gb/s, 64Gb/s, ...

• All VLBI to have an e-VLBI component:
  • Real-time quality checks and observation results
  • Use telescopes with less (or no) network bandwidth too
  • Record multi-Gb/s streams at telescopes,
    transport (as much as possible) real-time, record at correlator

• Real-time grid correlation:
  • Current grid not well suited for real-time high IO processing
Other e-VLBI projects

- Uniboard: FPGA based reconfigurable processing for radio astronomy
  - 16x 10Gb/s input and output
  - Internal interconnect at 20Gb/s
  - 8x FPGA (Altera Stratix 4 SGX230)
  - DDR-3 Memory
  - New correlator, receiver backend, pulsar processor, RFI filter

- New digital telescope backends, high-speed samplers, 4Gb/s and more
Questions?