Real-time e-VLBI developments in the EVN

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Currently, one large project in Metsähovi is EU EXPReS: improve VLBI in the EVN, faster turnaround, real-time results

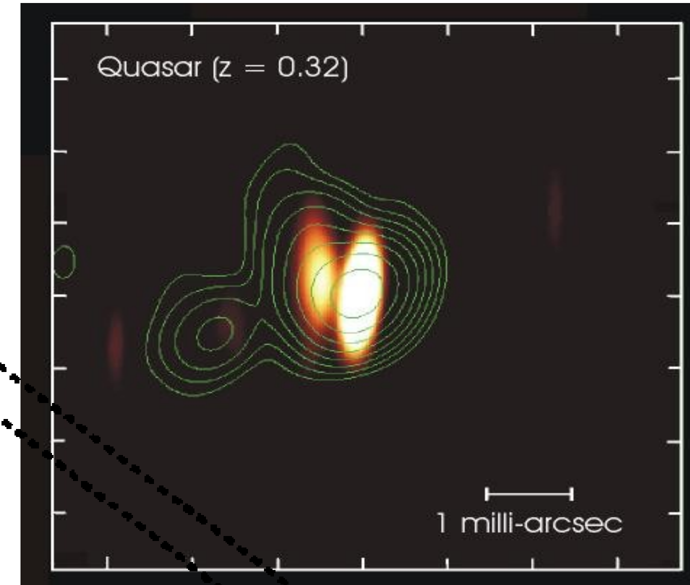
EXPReS tasks for Metsähovi:

1. data acquisition – official task!
2. high-speed Internet transfer – easy
3. station data processing – curiosity

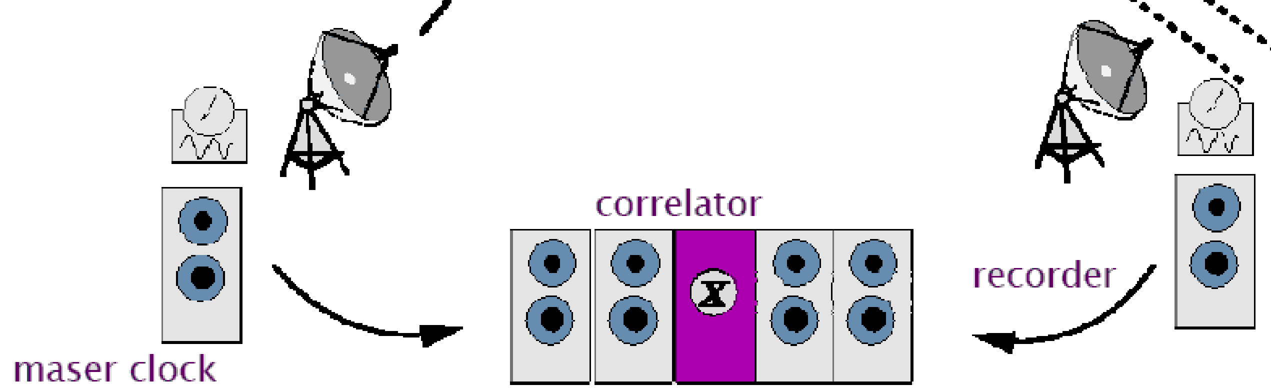
This work has received financial support from the European Commission (DG-INFSO), within the Sixth Framework Programme (Integrated Infrastructure Initiative contract number 026642, EXPReS).

VLBI Intro (1/2)

Very long baseline interferometry (VLBI):
- innovated in 1960ies in the US
- applies "old" aperture synthesis methods
- used by geodetics and astronomers



Consists of an array of telescopes:



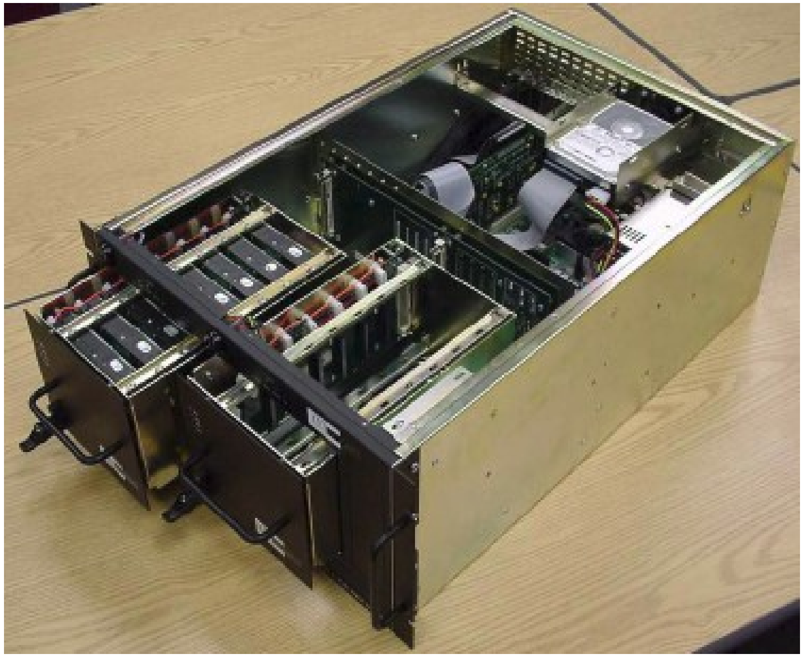
- telescope separation D=10 m ... 10^6 km very long vs wavelength λ
- interferometer has sub-milliarcsec resolution: $\theta \approx \lambda$ / baseline D

VLBI Intro (2/2)

How VLBI observations work in practice:
- all telescopes observe common sky sources
  - duration of measurement is several minutes per source
  - observing slices of radio spectrum around a GHz-range frequency
  - using wide slices (higher bandwidth) gives better sensitivity
- telescope data is recorded to tape or disk

Getting VLBI images:
- telescope data are sent via snail-mail to a correlator station
- images are calculated from full data

VLBI came from the US to Europe
=> European VLBI Network is still using US hardware a lot :
Mark5A, B, B+, C ; price >$10k



Better VLBI : e-VLBI

Silly to wait weeks or months to get the final images...
- physical transport of hard drives is expensive and slow
- feedback to stations about setup problems come too late, can't fix

The EVN astronomers and geodetics would like to have:
- more sources per VLBI session <=> shorter time per source
- improved sensitivity ΔS_v <=> increased bandwidth

$$\Delta S_{\upsilon} = \frac{\sqrt{2k_b T_{sys}}}{\eta_a \eta_c A \sqrt{\Delta t \Delta \nu} \sqrt{\frac{1}{2} N(N-1)}}$$

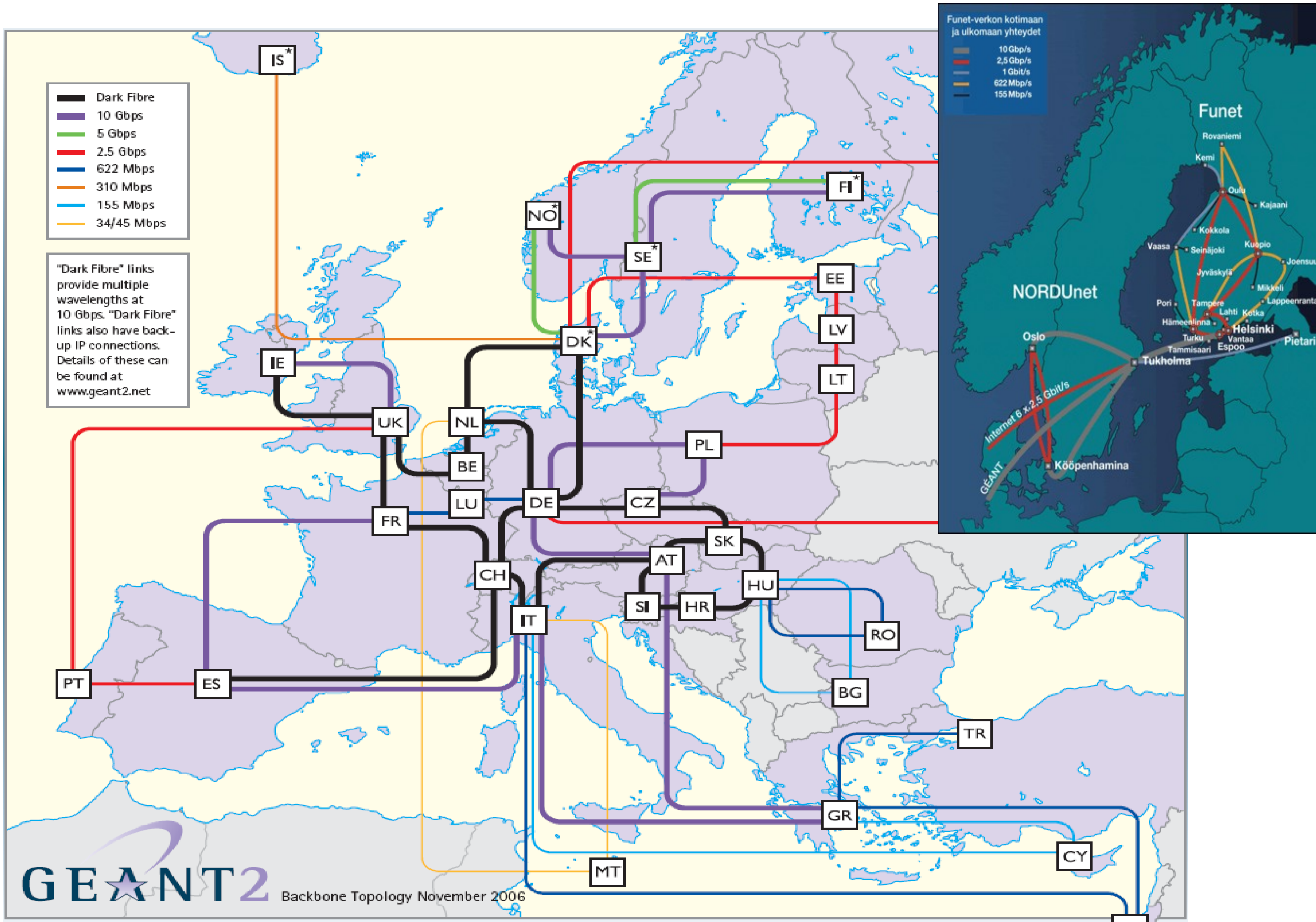
- instant VLBI images, real-time or same-day <=> real-time transfer

EXPReS **develops e-VLBI** which provides these in the EVN!

Real-time transfer-> Use Internet or research networks, not mail

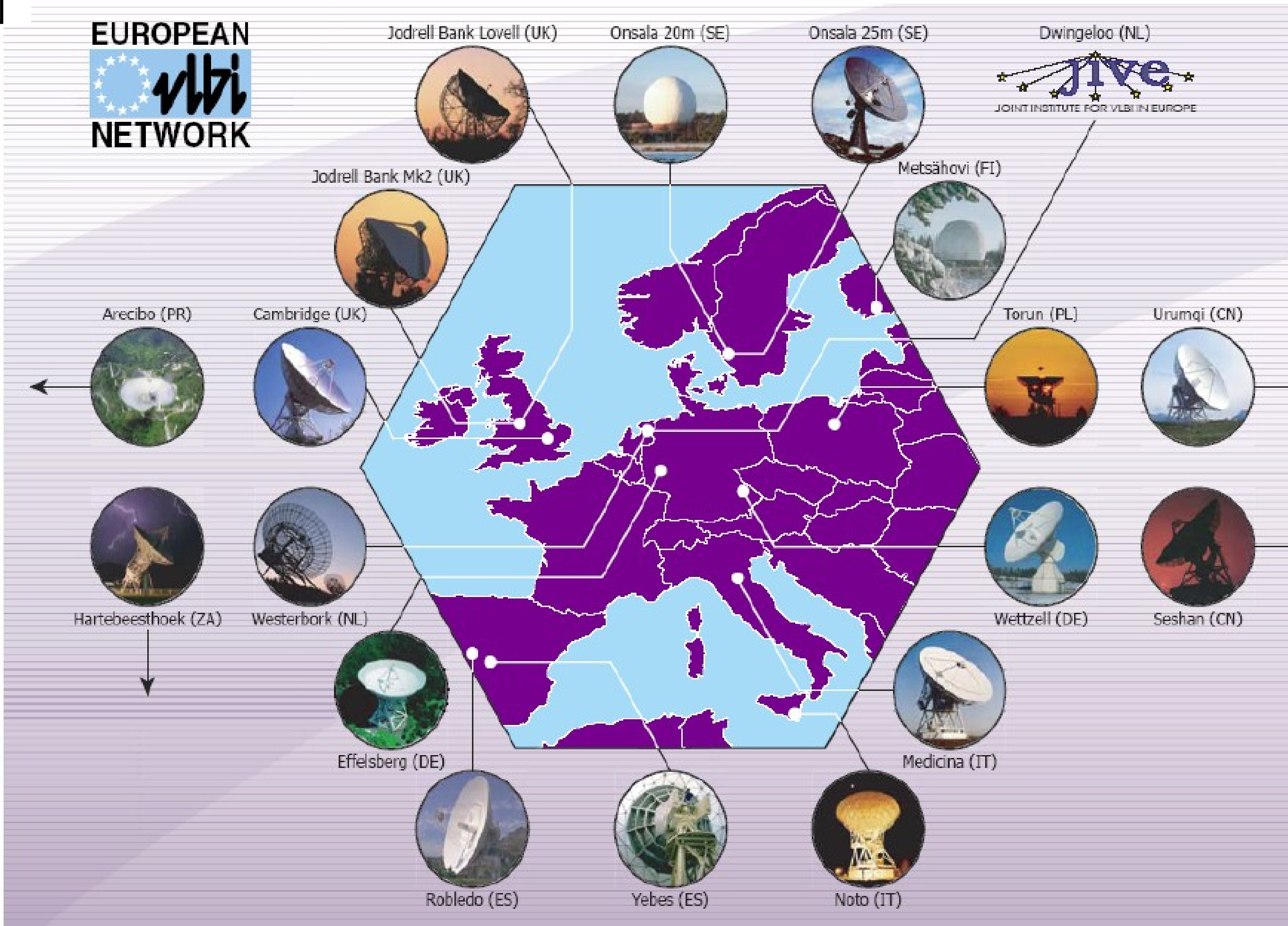
Increased sensitivity-> More data to transfer, so use fast networks

European research network

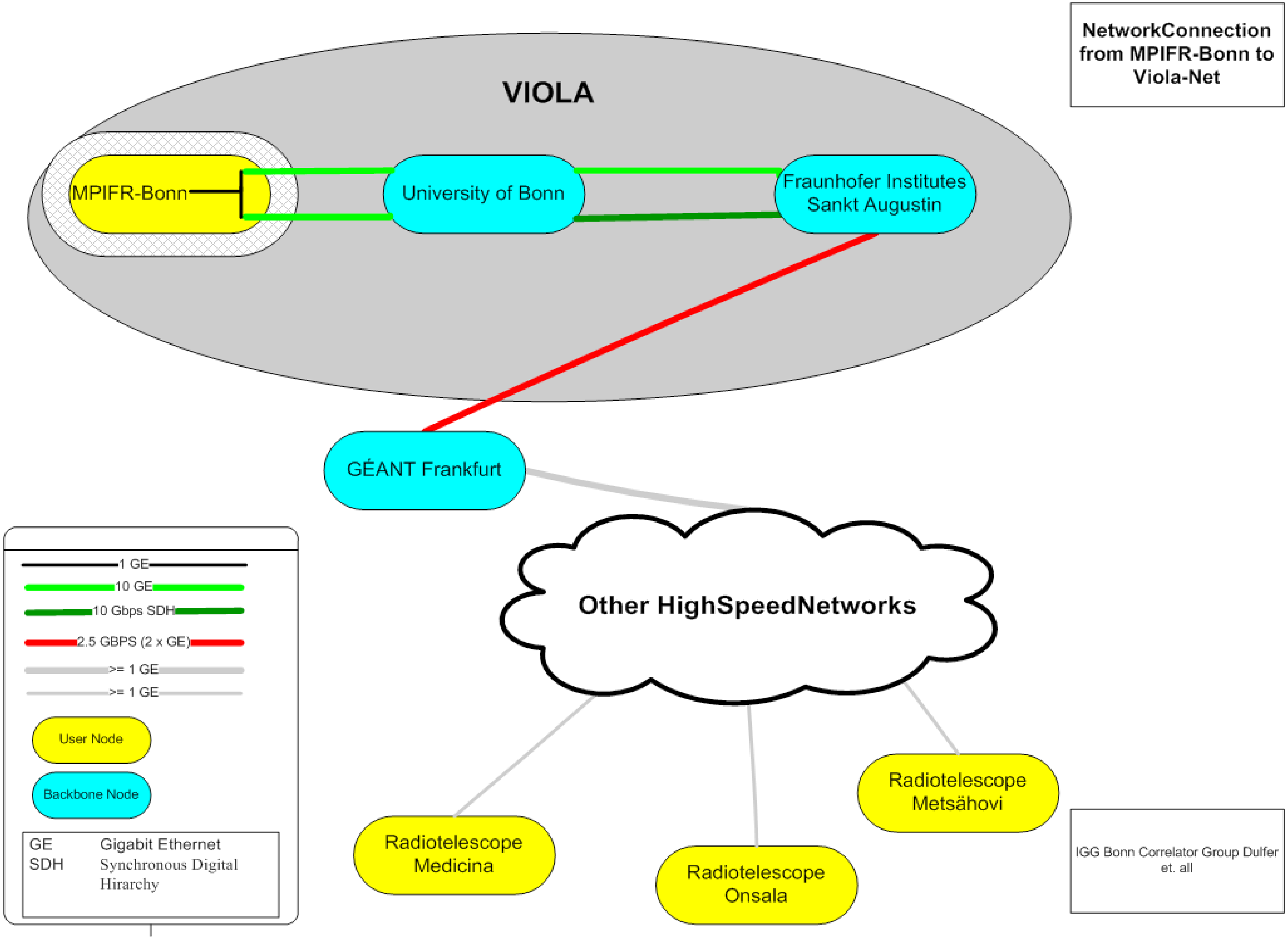


GÉANT2 is operated by DANTE on behalf of Europe's NRENs.

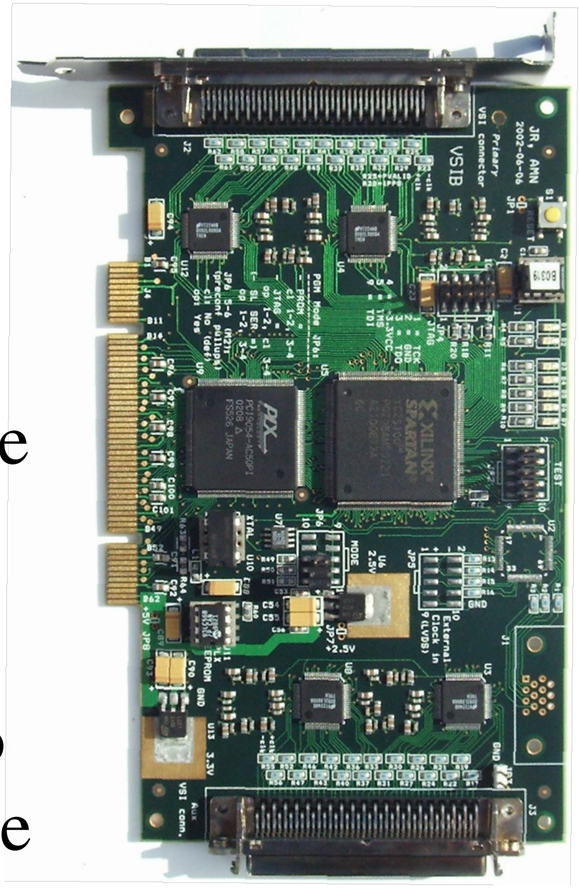
European VLBI Network



Geodetic e-VLBI topology example



Getting the data to the correlator...



In e-VLBI, need to get the data over in *real-time* for correlation. Several methods:

1) Mark5 data streaming by JIVE: still quite unreliable with many reboots needed, some 512 Mbps VLBI observations successful!

2) Metsähovi DAQ with VSIB, Tsunami protocol : versatile and reliable, used up to 896 - 1024 Mbps, slowly catching on in the EVN – especially in geo-VLBI

Future: new Metsähovi ultra-wideband data acquisition hardware for EXPReS. Based on Berkeley iBob board. Real-time antenna data streaming at up to 20 000 Mbps!

Tsunami transfer protocol

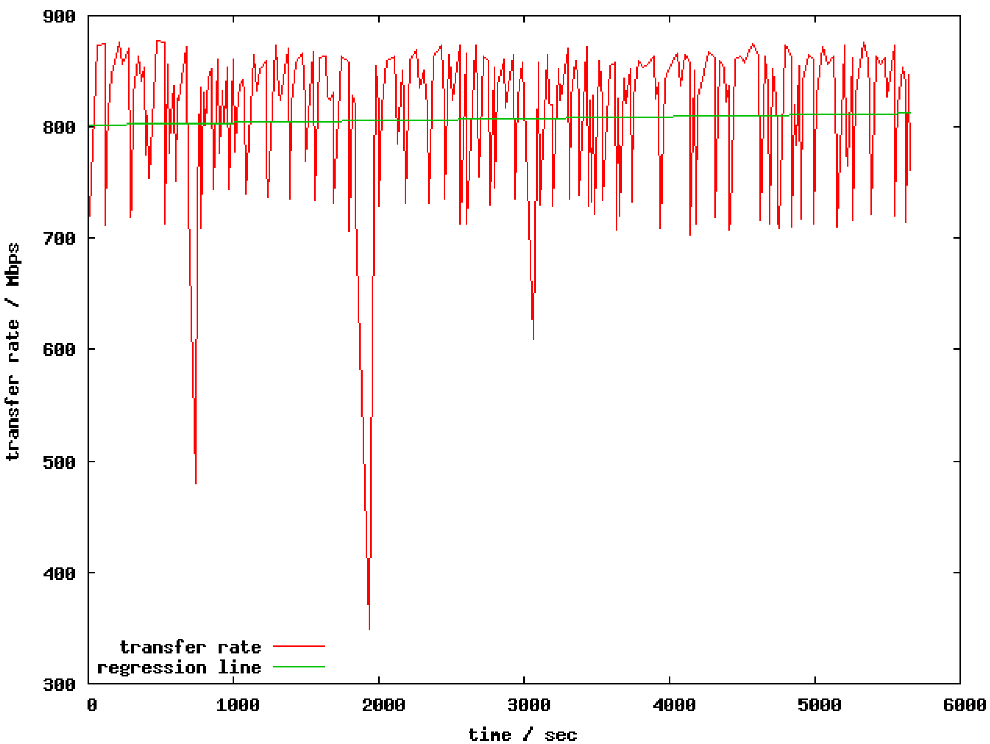
UDP-based high-speed transfer protocol, used for lossless transfer of multi-GB files, >10x faster than TCP. Metsähovi extensions allow real-time streaming of antenna data using the VSIB board - http://tsunami-udp.sourceforge.net/

Fast->	Office network 900 Mbps, Internet 800 Mbps typ.
Real-time->	Real-time up to 896 Mbps over Internet, Mh->Jb.
Reliable->	No data loss during more than 30 hours of non-stop real-time 512 Mbps transmission.
Applied->	*11/2006 :* 512 Mbps real-time VLBI officially demonstrated in EU demo, 896 Mbps transfer later *2007 Q1,2:* tens of 128 and 256 Mbps geo-VLBI sessions total (On, Mc, Mh, Bonn, Kashima). Short tests with other stations.

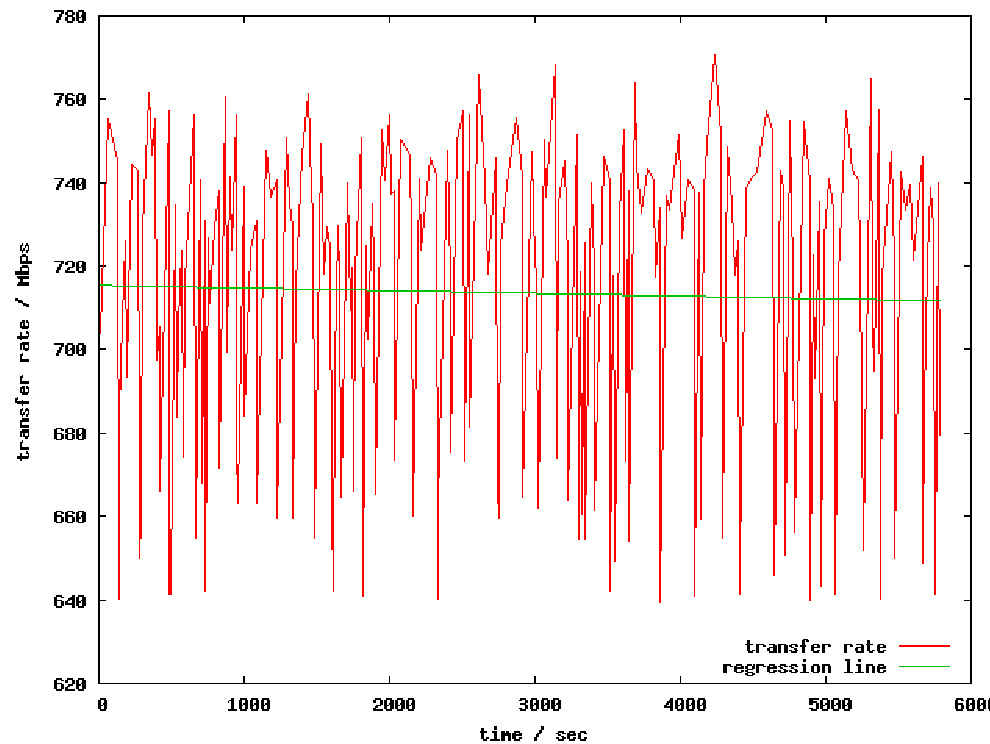
Summer 2007 : Norway, Wt, Ef, Tr, ... expected to join.

Example: off-line Tsunami of EURO85

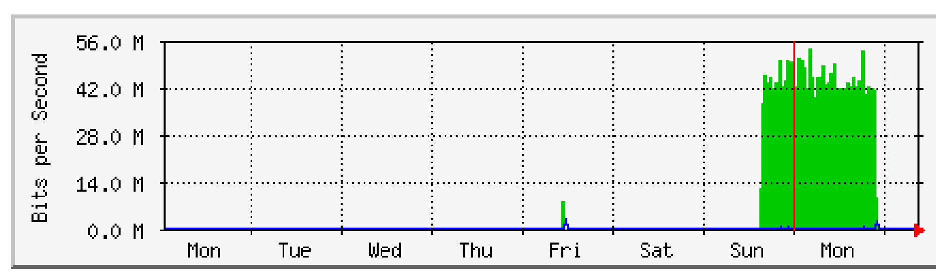
- Metsähovi, 572 GB from 24h
- Average throughput 806 Mbps, ~3.5h



- Onsala, 598 GB from 24h
- Average throughput 712 Mbps, ~4h

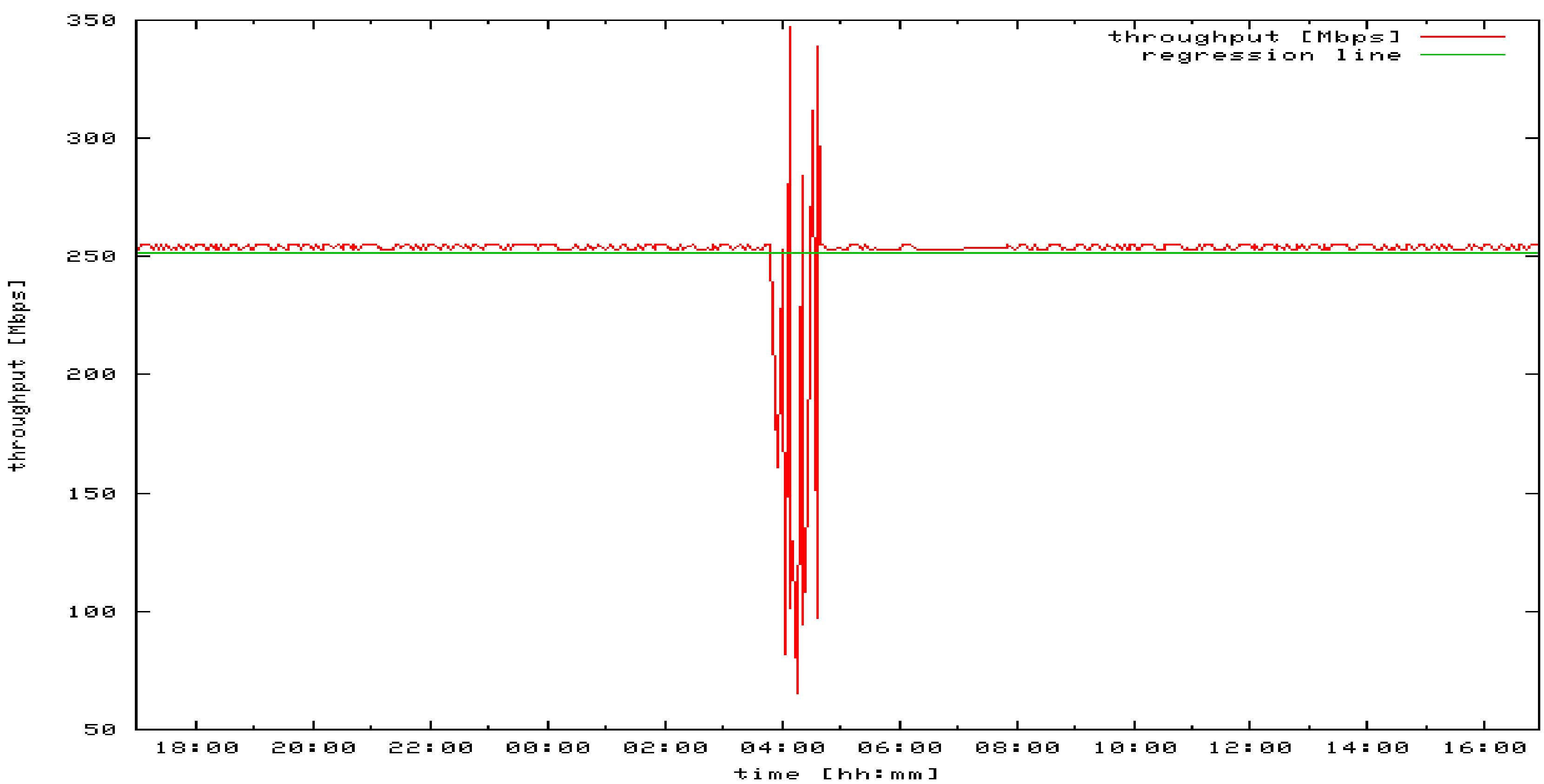


- Haystack EGAE software, Onsala
- Average throughput 94 Mbps, 31h



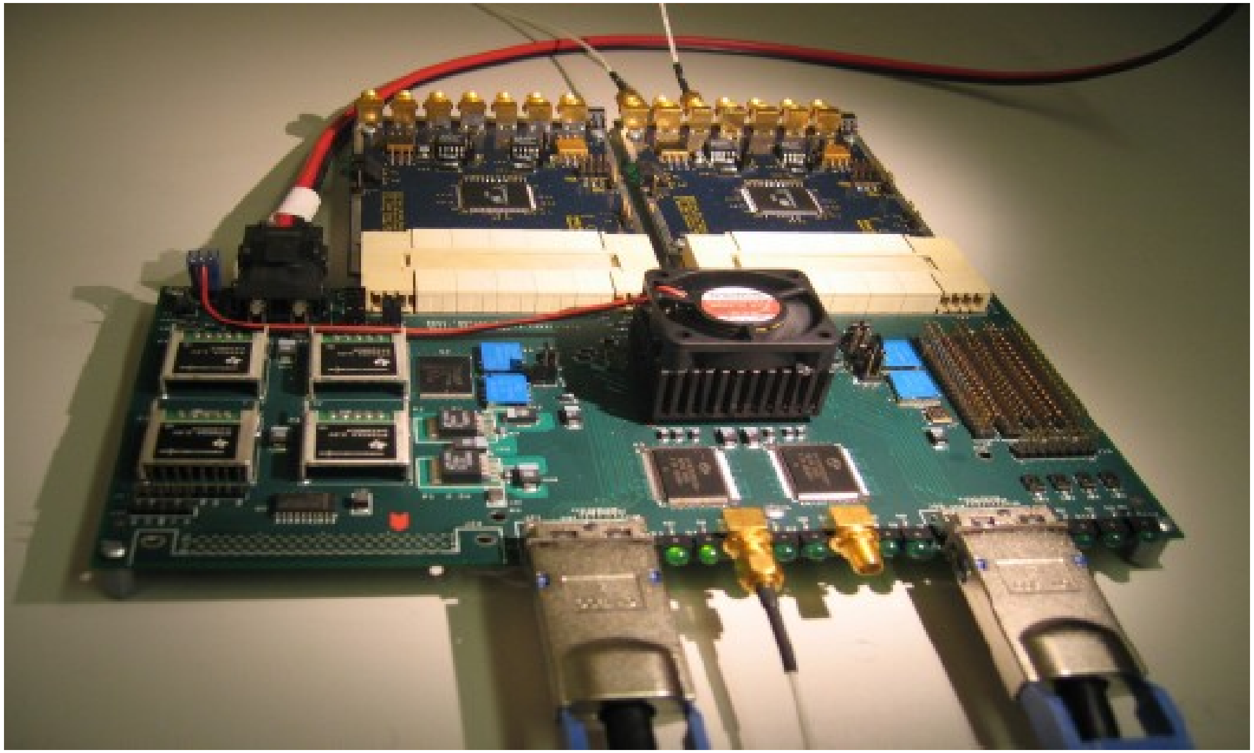
Example: real-time Tsunami of R1.265

- For developing software interoperability, several real-time geo-VLBI observations were tested at Metsähovi and Onsala in early 2007
- Feb07 R1.265 Onsala to Bonn : 256 Mbps mostly unattended smoothly for 24h, 2h glitch to make the plot interesting:



Improving e-VLBI sensitivity

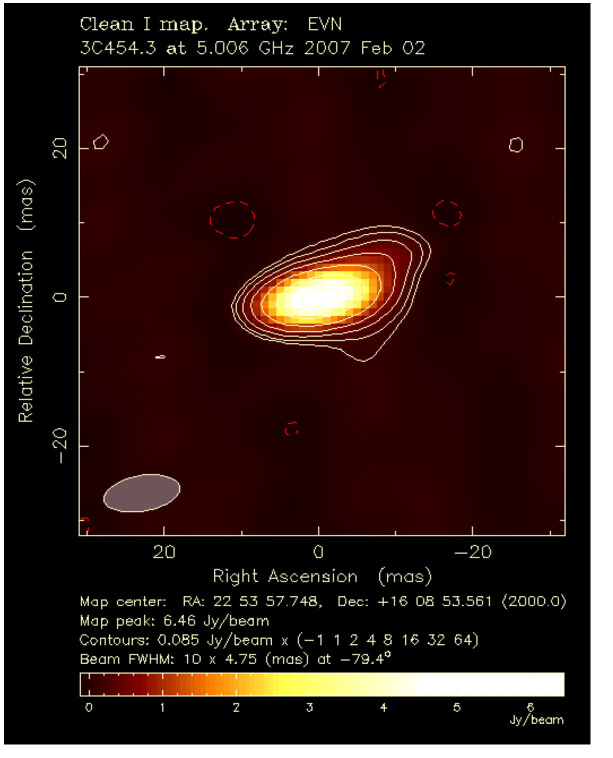
In EXPReS, Metsähovi is going to develop a ultra-wide bandwidth ≥4 Gbps DAS jointly with Jodrell Bank (UK).



Based on the inexpensive iBob board by UC Berkeley. Gigabit A/D samplers allow very wide bandwidth => much improved VLBI sensitivity! The 2x10 Gbps LAN makes it e-VLBI -ready.

Correlation for e-VLBI

Real-time data streaming at >=512 Mbps is working.
To be of any use, correlation and computation must be real-time, too!
=> EVN's correlator station JIVE is in the process of improving their hardware correlator



February 2007: first 1h e-VLBI with real-time correlation of 5 stations at 512 Mbps, JIVE.

March 2007: JIVE real-time fringes with 'new' Mark5 e-VLBI stations, 256/512 Mbps, Mh.

Basically two ways to do correlation calcs:

- Hardware correlation-> potentially very fast, ASIC or FPGA
- Software correlation-> slower but versatile, scalable, e.g. Matlab

Hardware correlation

This is the traditional way of correlating station data in the EVN.

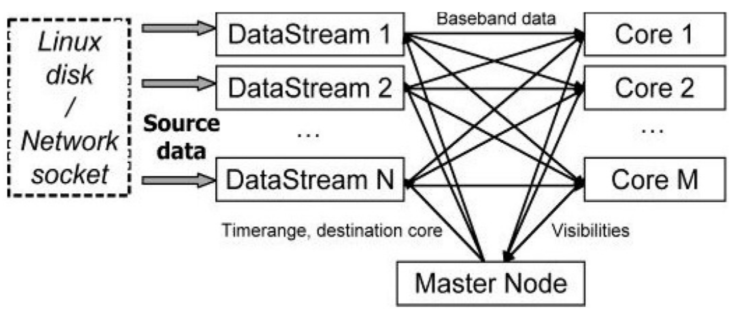
Hardware correlators work, **but** may be poor:

- poor scaling with # of stations and data rate
- custom hardware and microchips, expensive to upgrade
- proprietary interfacing, data input tied to special hardware
- correlator service providers in monopoly position, no competition

Software correlation (1/2)

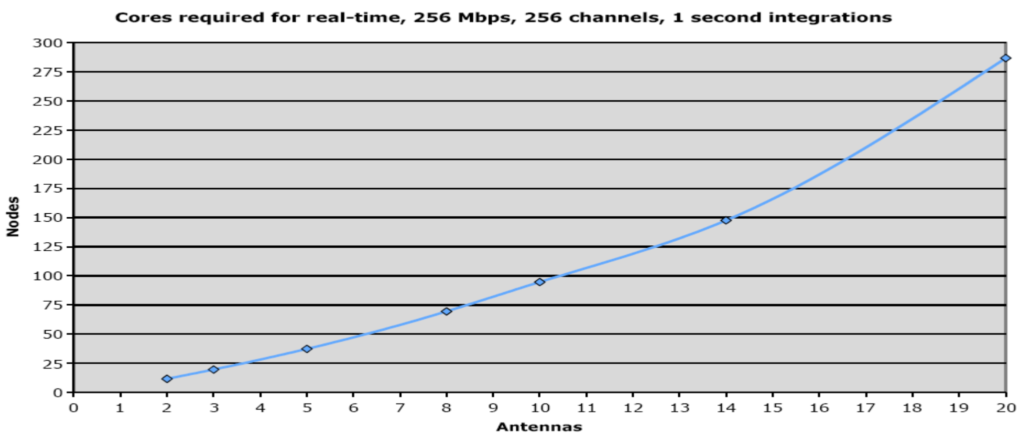
Software correlators are used all around the world, slowly in the EVN, too.
JIVE is currently researching distributed software correlation.

Benefits of software correlator:
- configurable, extendable, excellent scaling
- standard data input: office LAN, Internet, Grid
- can use commodity desktop PC cluster



Swinburnes free DiFX correlator:
- production quality (Sw, LBA)
- used for (geo-)VLBI, pulsar
- runs on Intel PC cluster

New DiFX users are MPIfR, NRAO/VLBA, ANTF/CSIRO, ...



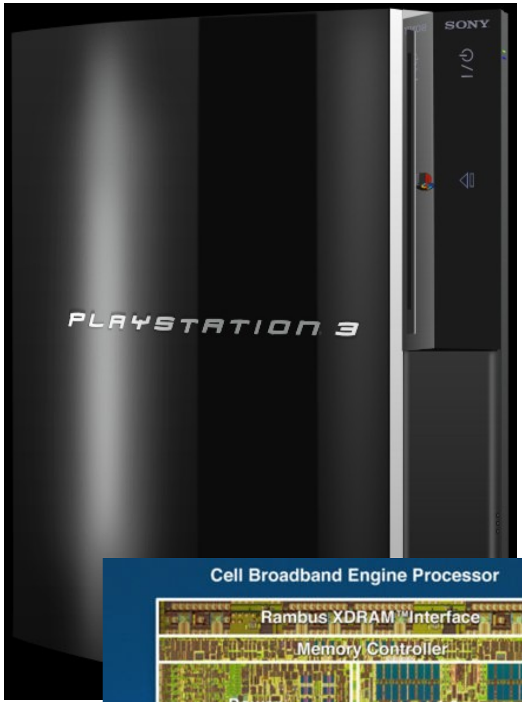
Software correlation (2/2)

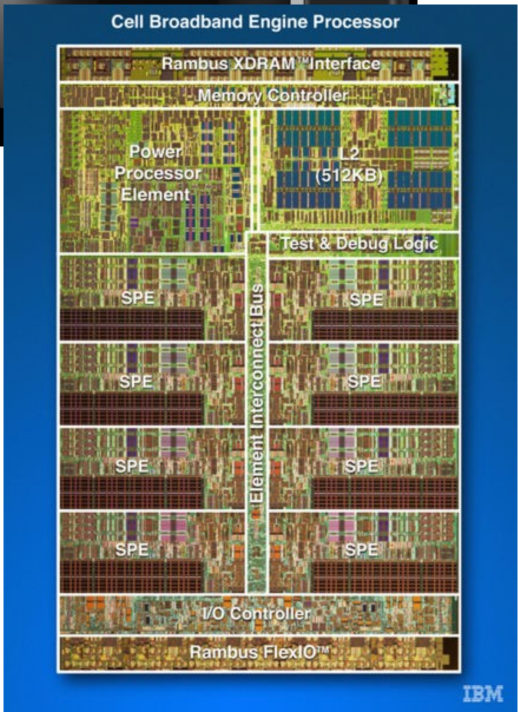
DiFX is being extended at Metsähovi, too.

Playstation 3 Cell beats current processors
in GFLOPs, IBM has free PS3 development kit.

DiFX platform-independent version:
- programming completed 01/2007

DiFX "PS3 Correlation@Home" version:
- already 800% optimized vs general version
- expecting to need 1/5th of PS3's vs PC's
- expecting real-time 256 Mbps correlation of 10 stations on 16 PS3's
- still some work to do this year





Conclusions

- In less than a year, many EVN stations have successfully started with e-VLBI data transfer. Competing Mark5 and Metsähovi Tsunami real-time transfer have been successful at 512 Mbps or higher.
- Improvements for real-time correlation progressing well.
- Real-time e-VLBI in the EVN is getting closer to production quality fast, promising for astronomers and geodetics : same-day results and better quality!
- At Metsähovi we will start to develop a ≥4 Gbps data acquisition system, includes e-VLBI data transfer.
- Metsähovi will also continue with e-VLBI software correlation experiments.