Third Period Report
EXPReS
Express Production Real-Time e-VLBI Service

Integrating Activity
implemented as
Integrated Infrastructure Initiative

Contract number: 26642

Project Co-ordinator: Huib Jan van Langevelde

Project website: http://www.expres-eu.org/

Reporting period: from 01 March 2008 to 31 August 2009

Project funded by the European Community
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Documet Log

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Project Information

Project Acronym	EXPReS
Project Full Title	Express Production Real-Time e-VLBI Service
Proposal/Contract number	DG-INFSO #026642

JIVE

AARNet

DANTE

PSNC

SURFnet

ASTRON

CNIG-IGN

CSIRO

NRF

INAF

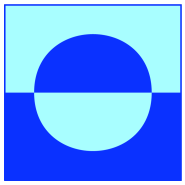
MPG

TKK

NAIC/Arecibo

UMK

OSO



ShAO

UdeC

UniMan

VeA/VIRAC

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SECTION A

1. Progress Report

1.1 Foreword

At the conclusion of the EXPReS project, it is particularly satisfying to observe the amazing amount of progress that has been made in the field of e-VLBI since its proposal was drafted in 2005. Not only have almost all the objectives of the original, ambitious project been met, moreover the work in EXPReS has gone beyond that, providing strong clues how VLBI and indeed radio-astronomy should take shape in the future.

The first objective of EXPReS was to implement an operational VLBI network capable of processing all incoming telescope signals in real time at 1 Gbps. While an operational system has been made available to the user community from the start, it has been possible to boost the data-rates to the 1 Gbps with the introduction of a number of upgrades in the second half of the project. Compared to the original plan, the network of European e-VLBI telescopes became complete in 2008 with the connection of the large Effelsberg dish and the new Yebes telescope.

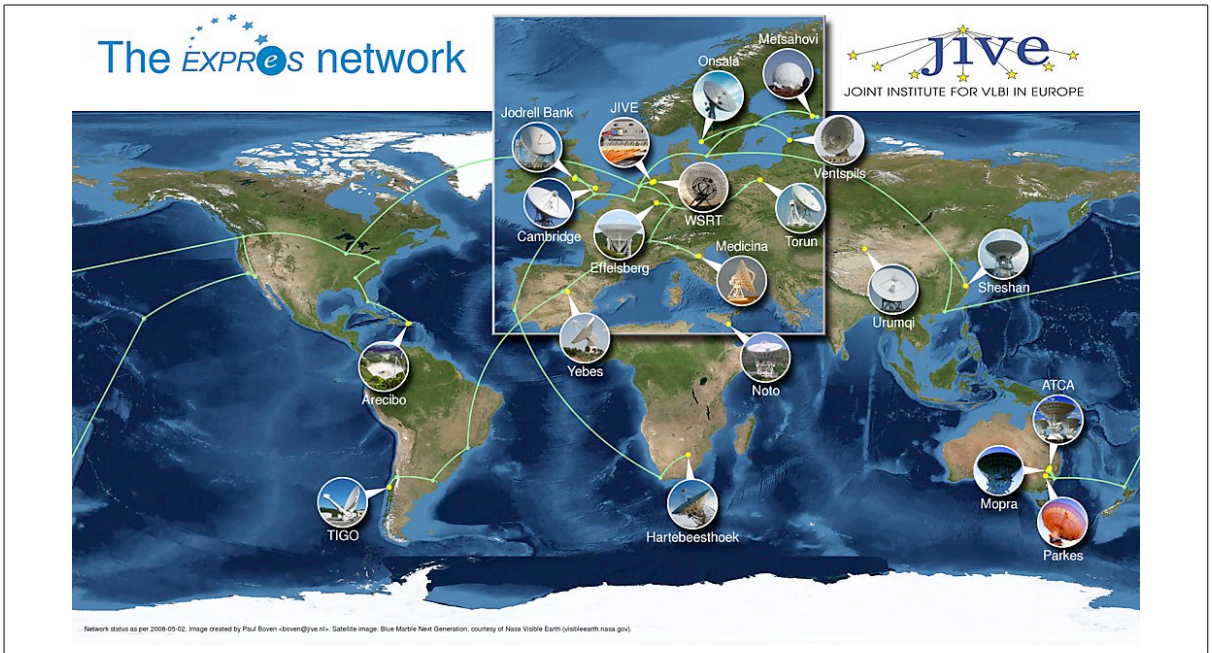


Figure X.1: EXPReS Telescope Locations

Of all the objectives in the Description of Work, I was personally most skeptical about the connectivity across continents. This hurdle was taken relatively early in the project with links to Australia, Africa, North- and South-America. This development has not been limited to doing impressive demos; regular observations with China are now routine. Tests are now also planned to include Russian telescopes; clearly the success of EXPReS has an attraction to observatories all over the world (see figure above). Moreover, the global, real-time network introduced by EXPReS for

demonstration purposes has recently been used in a science run, even before the service was formally made available to the scientific community.

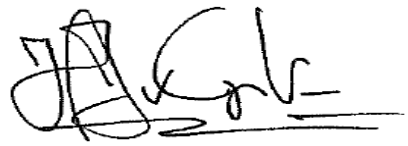
This last point demonstrates the most important achievement of the last 18 months of the project. Clearly the scientific use of e-VLBI has seen a tremendous increase. Intensive discussions in the eVSAG Network Activity have optimized the procedures for getting the best science out of the e-VLBI network. With the advent of more bandwidth and large telescopes, many astronomers were attracted to this new opportunity. Not only did the hours dedicated for e-VLBI experience a healthy proposal pressure, but numerous additional observations were triggered by "Target of Opportunity" proposals. This was another objective formulated in the original proposal. Currently work is progressing on several high impact publications that demonstrate the success of EXPReS for astronomy.

More scientific use is still anticipated with the e-EVN eMERLIN combination. The digital interfaces for this have successfully been developed in the EXPReS context, but the commissioning of these features has been postponed because of delays with the new eMERLIN correlator. The user demand for this feature is high and therefore it is beyond any doubt that the EXPReS work will result in new science in this area too.

On the whole, however, the Joint Research Activity FABRIC has published its deliverables and has gone beyond these in several areas. This work has made an invaluable contribution to the technical expertise in the VLBI community, strengthening the expertise in computing and digital processing in addition to the networking expertise that came through the Service Activities. From this work important conclusions have been drawn that are relevant for the future shape of not only VLBI arrays but also new radio-astronomy facilities like eMERLIN, LOFAR and the SKA.

Looking at what EXPReS has been able to achieve, it has become clear that e-VLBI has a bright future. Not only does it enable new science, but by deploying a number of networking techniques and protocols, it has also proved to be incredibly robust and ready to upgrade to higher bandwidths. This calls for the further development of an e-VLBI facility that can be deployed for all science observations, enabling more sensitivity, flexibility and reliability for astronomical experiments. This is the subject of the new NEXPReS proposal, currently being developed by the EXPReS partners.

The key of the success of EXPReS has been the enthusiastic collaboration of highly skilled people from different domains. This collaboration between astronomers and network providers has brought together a wide range of talents working together on a highly exciting and appealing project. Additionally, EXPReS has been successful in setting up an effective and focused management structure, carrying out the reporting, finances and outreach responsibilities. This final report is a testimony of the skill and enthusiasm of all professionals in the EXPReS project.



Huib Jan van Langevelde

1.2 Summary of Major Activities and Achievements

EXPReS, **Ex**press **P**roduction **R**eal-time **e**-VLBI **S**ervice, is a 42 month project funded via the European Commission's Sixth Framework Program with the objective to improve the capabilities of e-VLBI by connecting telescopes around the planet to the shared e-infrastructure, establish new operational tools and research the techniques and technologies that will improve science over the coming years. Over the course of the project, we have seen significant improvements in all of these categories.

The figure below highlights some of the major activities of the past period. e-VLBI sessions and triggered sessions have increased in frequency compared to previous periods and they are as reliable as traditional VLBI (the equivalent diagrams for periods 1 and 2 are provided for reference in the annex of this report). Demonstration events held over the course of the project also helped showcase the work both inside the e-VLBI community and to the world at large.

Looking back over the past period, several events stand out and are worth mention. The Effelsberg connection event is important for bringing the largest telescope in Europe online. The event brought together members of the project as well as representatives from the EC and the local media.

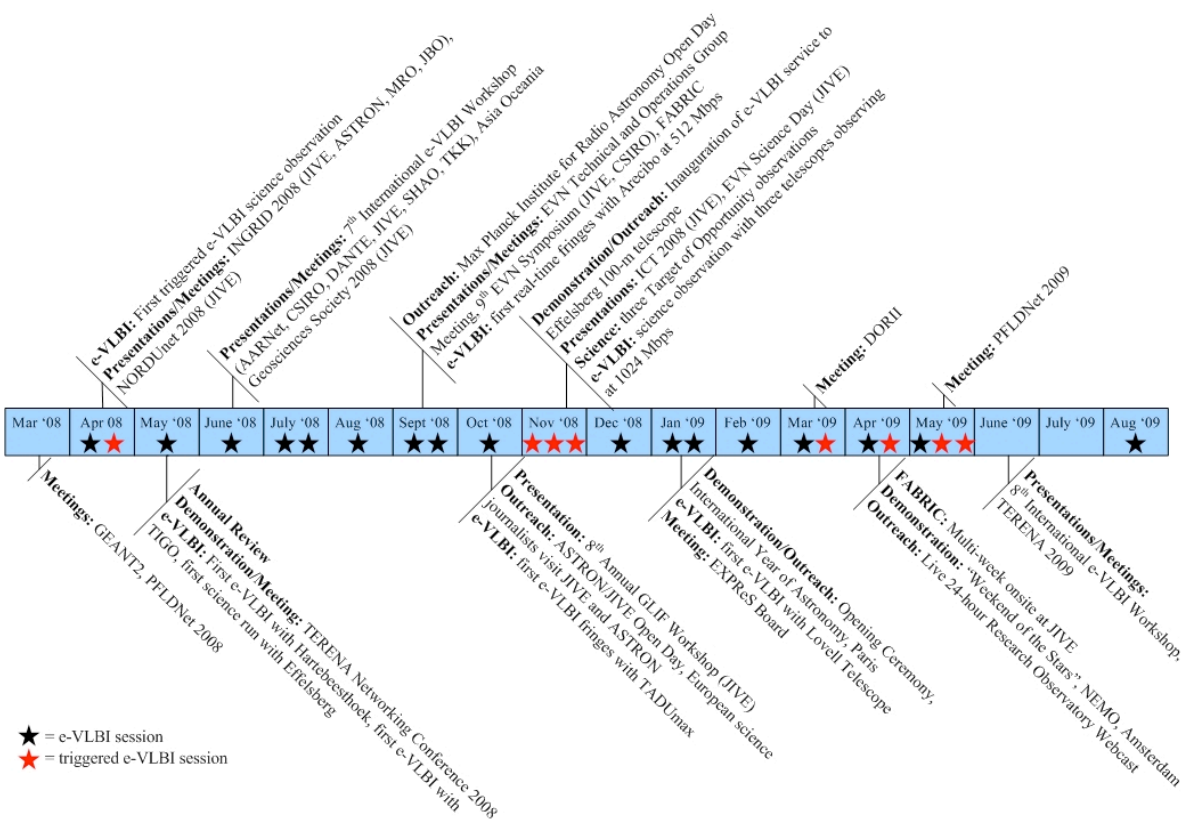


Figure: Timeline of major EXPReS events over the past 18 month period.

The International Year of Astronomy 2009 kickoff activities were also important for showcasing e-VLBI and the efforts of the EXPReS partners on the global stage. Huib Jan van Langevelde provided a presentation during the kickoff event in Paris.

The end-of-project-meeting, executed as part of the annual e-VLBI workshop series, was also important because it was an opportunity to showcase the accomplishments of EXPReS in relation to the other activities in the community. EXPReS is conducting the type of astronomy that the community hopes to do in the years to come. We are creating the tools that will be used in the future and identifying ...

Most importantly, the number of publications that have been published or are in process highlight the attractiveness of the service that is now available (the NA3 and SA1 sections of this report highlight science activities and the publications are listed in section 3.2 List of Publications). The publications highlight not only the core science, but also the rapid response abilities of e-VLBI.

1.3 Management Activity

1.3.1 NA1 Management of I3

1.3.1.1 NA1 Activity and Status

EXPReS is a 19 member project coordinated by JIVE, the Joint Institute for VLBI in Europe. The project coordinator and the project office are located at JIVE and have provided oversight for the project. The Board of Directors provides high level management of the project and meets annually at the Board Meeting. The project's partners and current Chair and Vice-Chair are identified in the table below.

#	Institution	Board Member's Name <email address>
1	JIVE	Huib Jan van Langevelde <langevelde@jive.nl>, Coordinator
2	AARNET	Chris Hancock <chris.hancock@aarnet.edu.au>
3	DANTE	John Chevers <john.chevers@dante.org.uk>
4	PSNC	Norbert Meyer <meyer@man.poznan.pl>
5	SURFnet	Kees Neggers <kees.neggers@SURFnet.nl>
6	ASTRON	Marco De Vos <devos@astron.nl>
7	CNIG-IGN	Rafael Bachiller <r.bachiller@oan.es>
8	CSIRO	**Tasso Tzioumis** <tasso.tzioumis@csiro.au>, **Chair**
9	HARTRAO	Roy Booth <roy@hartrao.ac.za>
10	INAF	Piero Benvenuti <benvenuti@inaf.it>
11	MPIfR	Anton Zensus <azensus@mpifr-bonn.mpg.de>
12	MRO/TKK	Ari Mujunen <amujunen@cc.hut.fi>
13	NAIC/Cornell	Robert Brown <bbrown@astro.cornell.edu>
14	NCU/UMK	Andrzej Kus <ajk@astro.uni.torun.pl>
15	OSO	John Conway <jconway@oso.chalmers.se>
16	ShAO	Xiaoyu Hong <xhong@center.shao.ac.cn>
17	TIGO/UDEC	Hayo Hase <hayo.hase@tigo.cl>
18	UniMan	**Ralph E. Spencer** <res@jb.man.ac.uk>, **Vice-Chair**
19	VIRAC	Juris Zagars <yzh@venta.lv>

Over the past reporting periods, the project has gained a great deal of experience and improved internal processes. The most recent board meeting <http://www.jive.nl/dokuwiki/doku.php?id=expres:expres> highlighted this fact with the ability to move quickly through a large agenda with enough time to discuss and feel well informed about the decisions that were made. At the meeting, many agenda items that were slow in the intial meetings have been turned into process.

The meeting provided an opportunity to highlight issues to be considered for future projects within the community. Some partners described what they felt were difficult burdens in terms of reporting and

funds matching. Inside the project, we have discussed unspoken assumptions during the creation of the original contract as well as how to learn from this for future efforts. We have also to report that one of our partners found it more efficient and effective to participate without partaking in the Commission funds. This is important again to the design of future efforts as we identify fund amounts with respect to existing and required efforts within the project contract.

EXPReS: Activities

EXPReS is divided into three activities: Networking, Specific Service and Joint Research. There are four NAs, two SAs and one JRA as listed in the table below. Also listed are the individuals responsible for the activities.

Activity	Name	Organization
PC	Huib Jan van Langevelde	JIVE
NA1	T. Charles Yun	JIVE
NA2	John Conway	Onsala
NA3	John Chevers	DANTE
NA4	Kristine Yun	JIVE
SA1	Arpad Szomoru	JIVE
SA2	Francisco (Paco) Colomer	CNIG-IGN
JRA1	Huib Jan van Langevelde	JIVE

Note that Huib Jan van Langevelde is listed both as leader of JRA1 as well as the Project Coordinator. While formal head of JRA1, his duties as Project Coordinator have lead him to delegate day to day responsibilities to Charles Yun and Mark Kettenis.

Reporting and Distribution of Finances

As part of the core duties of the Project Office, regular reporting and distribution of finances were carried out over the past period. Monthly reports posted to the wiki[1] highlight the detailed progress of the project. Project deliverables are also tracked and posted to the wiki (hard copies for this period are delivered along with this report).

Project finances were distributed after the tranche was received from the Commission in November 2008. The funds were distributed based on the data reported on the Form C from each of the partners and according to adjustments agreed to during the project's Board Meeting on 21 January 2009 held in Madrid, Spain. The adjustments are all internal and budget netural as shown by the table below.

	Adjustments			
	Period 1	Period 2	Period 3	Net
JIVE	(2,000 €)	(11,000 €)	55,500 €	42,500 €
AARNET		5,000 €	(5,000 €)	0 €

[1] The reports are available to registered users via the URL: <http://www.jive.nl/dokuwiki/doku.php/expres:management:mt>. Username/passwords have been shared with appropriate parties. New username/password combinations can be requested online via the wiki interface.

DANTE			0 €	0 €
PSNC		5,000 €	10,700 €	15,700 €
SURFnet			(5,700 €)	(5,700 €)
ASTRON	(2,000 €)		(3,000 €)	(5,000 €)
CNIG-IGN	(3,000 €)		(14,500 €)	(17,500 €)
CSIRO	15,000 €		(2,500 €)	12,500 €
NRF	(2,000 €)	20,000 €	(18,000 €)	0 €
INAF	(2,000 €)		(23,000 €)	(25,000 €)
MPIfR		(50,000 €)	37,500 €	(12,500 €)
TKK			(9,500 €)	(9,500 €)
CORNELL	(2,000 €)		2,000 €	0 €
UMK			(5,000 €)	(5,000 €)
OSO			(17,500 €)	(17,500 €)
SHAO	(2,000 €)		2,000 €	0 €
UDEC			0 €	0 €
UNIMAN			0 €	0 €
VeA/VIRAC		31,000 €	(4,000 €)	27,000 €
total	0 €	0 €	0 €	0 €

Contract modification

During the final period, the project received word that modifications of the contract had been received and accepted by the Commission. The changes involved two very different issues. The first issue was a 6 month, no cost extension to the project. The second change had to do with a change in the interpretation and understanding of the legal status of partner CNIG-IGN.

Final EXPReS Board Meeting

The final EXPReS Board Meeting was held in Madrid, Spain on Wednesday 21 January 2009. Our partner CNIG-IGN helped to organize and host the meeting. The final meeting included update presentations from each of the activities as well as a discussion on the project's finances as we approached the end of the project. The meeting was coordinated to be contiguous with the SKADS Board Meeting as several individuals participate in both meetings.

The meeting agenda, presentations and minutes are available on the project wiki via <http://www.jive.nl/dokuwiki/doku.php/expres:fourth_board_meeting>. A short summary is available as an annex to this report.

Coordinatorship

In the closing month of the project, Huib Jan van Langevelde sent a note to the project's Science Officer, Jean-Luc Dorel, indicating that he would delegate all of his project responsibilities due to a personal emergency. The email indicated that Arapad Szomoru would take the responsibility of EXPReS Coordinator and Leonid Gurvits would take the responsibility as JIVE Director. The day to

day operations of the project should not be chnaged at all, but this does mean that van Langevelde is not expected to be available for the final review.

1.4.3.2 NA1 Participating Institutions[2]

The majority of NA1 activity takes place at JIVE with the employment of the EXPReS Public Outreach Officer, and production of publicity materials. Each of the 19 partners in the project participate as members of the NA1 activity.

#	Short Name	P3 Claim (EUR)[3]
1	JIVE	65,329.38
2	AARNet	0.00
3	DANTE	0.00
4	PSNC	0
5	SURFnet	0.00
6	ASTRON	0.00
7	CNIG-IGN	0
8	CSIRO	0.00
9	NRF	0.00
10	INAF	0.00
11	MPIfR	1,885.47
12	TKK	2248.57
13	Cornell	0.00
14	UMK	0
15	OSO	0.00
16	ShAO	0.00
17	UdeC	0.00
18	UniMan	1,639.45
19	VIRAC	0
	total	75,996.10

[2] Participation is based on those institutions who have received funding for the activity. The Participating Institution Table assumes the following abbreviations:
P # - Participant Number

[3] Period 3 figures are based the most accurate figures available at the time of writing. Many partners were in the process of their audits and expect changes to these figures. Official figures will be provided as soon as they are available.

1.4.3.3 NA1 Deliverables and Milestones Tables

The final deliverables for NA1 are related to the documentation and reports related to the ending of the project. Each of the deliverables below are included in the final report (this document), as an appendix or as a supporting document with the final report.

D#	AD#	Deliverable Description	Lead	Delivery Month		Status[4]
				Planned	Actual	
111	1.03	Annual report (incl. Financial information) to EC	JIVE	42	42	4
112	1.04	Final Report to Board and EC	JIVE	42	42	4
113	1.05	Final Plan for using and disseminating knowledge	JIVE	42	42	4
114	1.06	Implementation of the Gender Action Plan	JIVE	42	42	4
115	1.07	Raising public participation and awareness	JIVE	42	42	4
200	1.08	Month 42 Report (including financial information to EC)	JIVE	42	42	4

1.4.3.4 NA1 Human Resource Overview

The parties participating in NA1 have not changed in the past period. The Project Manager and Administrative Assistance continued their work from JIVE's facilities. Note that during the preparations for and immediately after the Madrid e-VLBI workshop, the Administrative Assistant booked some time against the NA3 activity to reflect the short term, large volume of work executed in support of that meeting. Also, in association with Huib Jan van Langevelde's change in position to JIVE Director, the Project Manager shifted a portion of his time to assist in FABRIC management.

Position Title	Position Location (Short Name)	Position Description	Start Month
Project Manager	JIVE	Project management @ 0.5 FTE	6
Administrative Assistant	JIVE	Project support @ 0.5 FTE	1

1.4.3.5 NA1 Meetings and Workshops

Date/Location	Meeting Title / Subject / Website Address	# Attendees
21 Jan 2009 Madrid, Spain	Final EXPReS Board Meeting http://www.jive.nl/dokuwiki/doku.php/expres:fourth_board_meeting	~20
22 June 2009 Madrid, Spain	Final EXPReS Board Meeting End of Project Conference: the 8the International e-VLBI Workshop Capstone meeting with presentations on astronomy science and technology enabled by and related to EXPReS http://www.oan.es/expres09/	~80

[4] The status of the deliverable is tracked on a 0 to 4 scale with 0 indicating no work started and 4 indicating that the deliverable has been accepted by the project office.

1.4.3.6 NA1 Participation in External Events

EXPReS continues to be an active participant in the astronomy and networking communities as would be expected. EXPReS partners also participate in a variety of related outside efforts. Many of these can be identified in the presentations and papers section of this document. Below are highlights from meetings and activities in which the Project Office participated directly.

Event/Organization	Type of participation
DORII, March 2009	participation on DORII Advisory Board
8th International e-VLBI Workshop, June 2009	organization and execution of the entire workshop
International Year of Astronomy 2009, multiple events over 2009	real-time demonstration, presentation and interaction with the organizers at kickoff meeting; participation in ongoing year-long event schedule; real-time demonstration and presetation at Dutch IYA event
INGRID 2009	Presentation
AOGS 2008	AOGS 2008 (Asia Oceania Geosciences Society), 16-20 June 2008 Busan, Korea. http://www.asiaoceania.org/aogs2008/. Presentation.
ICT 2008	ICT 2008, 25-27 November 2008. Lyon, France. http://ec.europa.eu/information_society/events/ict/2008/index_en.htm
Effelsberg Inauguration	Effelsberg, Germany, November 2008. EXPReS and MPIfR hosted a reception to inaugurate the 100-m radio telescope at Effelsberg into the e-EVN. The project office and EC Science officer participate in the event.
TNC 2008	TERENEA Networking Conference, 2008. Brugge, Belgium. EXPReS demonstrations, presentations and keynote talk by Coordinator.
7th International e-VLBI Workshop	e-VLBI Workshop, Shanghai, China. The project office assisted in the organization and execution of this event. Multiple EXPReS presentations and demonstrations were given.

1.4 Networking Activities

1.4.1 NA2 - EVN-NREN Forum

The EVN-NREN forum consists of both a physical meeting, held approximately annually, and a virtual forum by way of an email list. The list is subscribed to by 38 members of the networking and radio astronomy communities. Regular discussion takes place on issues of interest to these individuals specifically on topics relating to network implementation to telescopes and performance experienced by e-VLBI traffic.

1.4.1.1 NA2 Activity and Status

NREN Participants

EXPReS is not purely an astronomical activity. EXPReS includes in its partners four networking organisations.

DANTE

DANTE is the operator of a number of regional research network backbones: GÉANT2, ALICE, ORIENT, and TEIN2.

In Europe GÉANT2 connects 34 countries in Europe with a high-bandwidth IP network and also offers dedicated circuits of between 1Gbps and 10Gbps for data-intensive research projects. In addition, GÉANT2 provides connectivity to other world regions, with connections to the USA, South Africa and India and others. The majority of European telescopes are now connected to the Netherlands via GÉANT2. The GÉANT2 testbed and the GÉANT Plus network have been used extensively for testing high data-rate flows on a pan-European scale.

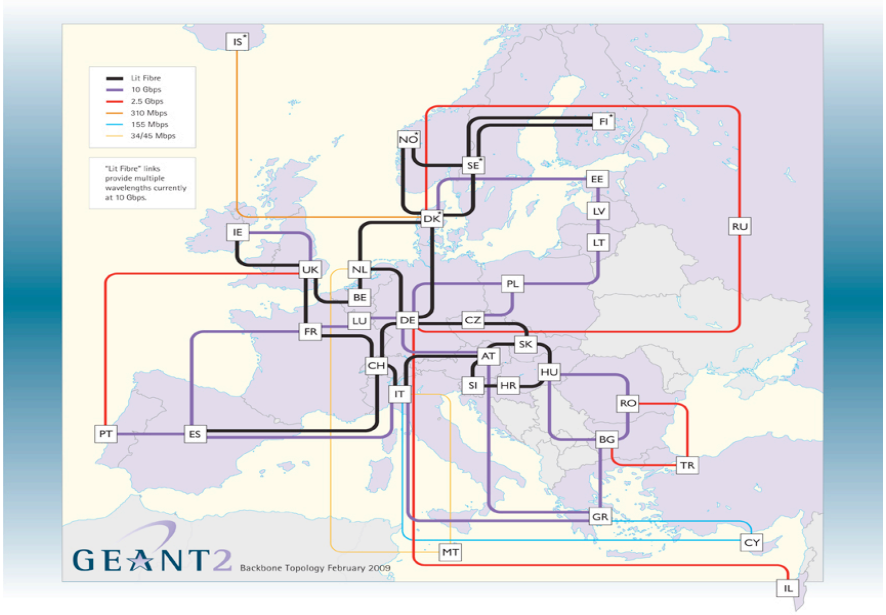


Figure: GÉANT2 Network Map

ALICE is the project which created the RedCLARA network in Latin America. This network connects 14 national networks in the region and provides a link to GÉANT2 in Europe. In the context of EXPReS, RedCLARA provides connectivity to the TIGO telescope in Chile.

ORIENT is a project dedicated to providing a high bandwidth connection between research networks in Europe and China. The Shanghai astronomical Observatory has used this circuit to connect to Europe.

TEIN2, a network connecting Asia-Pacific countries and EUMEDCONNECT, a network connecting Mediterranean and North African countries. These networks are available to EXPReS for data distribution or the connection of new telescopes.

SURFnet

SURFnet is the national research and education network of the Netherlands and provides connectivity via their SURFnet6 for access inside the Netherlands and from the Netherlands to international networks. SURFnet is a member of the GÉANT2 consortium and a partner in the TEIN2 project. SURFnet connects both JIVE (Dwingeloo) and ASTRON (Westerbork).

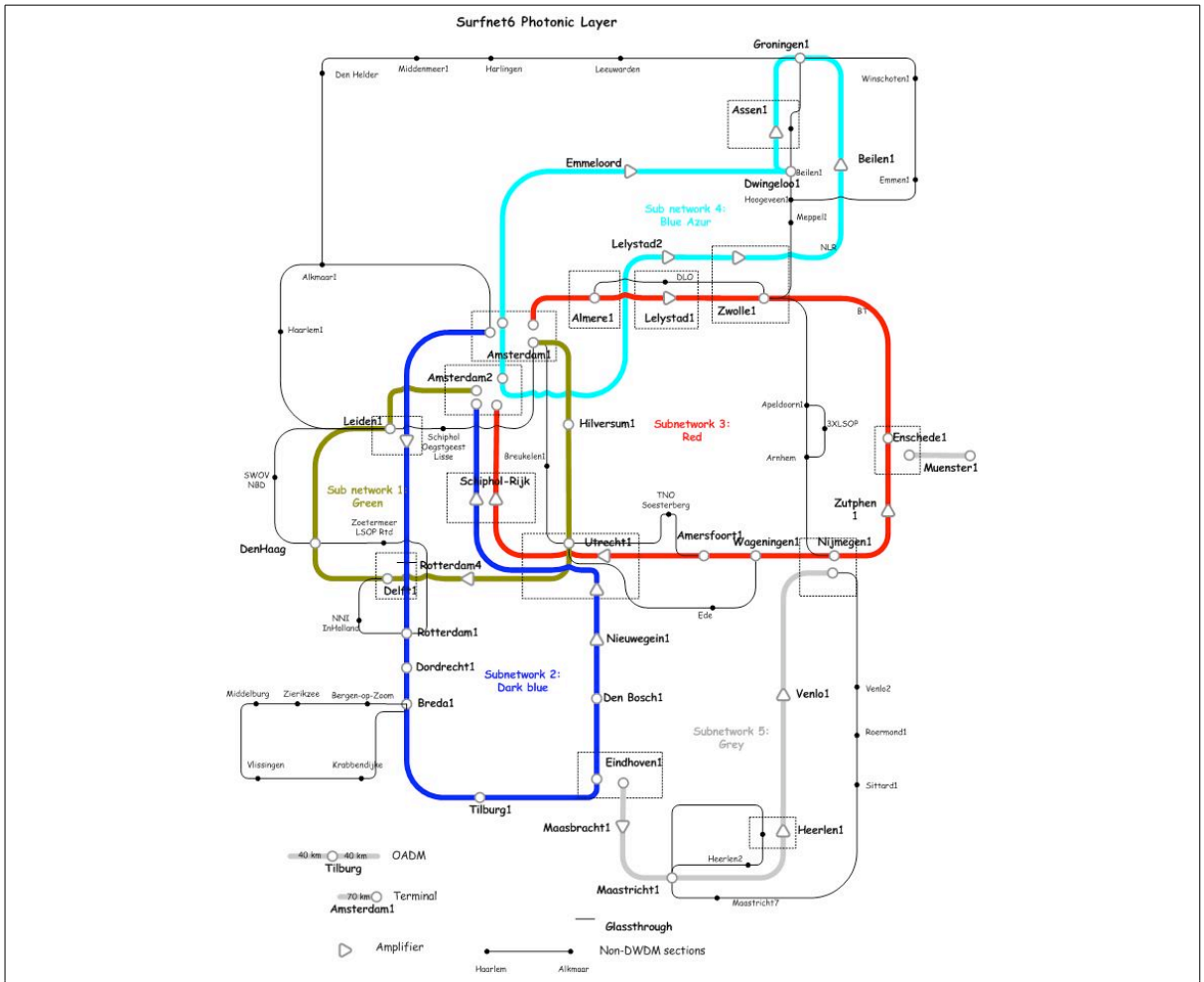


Figure: SURFNet 6 Network Map, Photonic Layer

AARNET

AARNET is the national research and education network of Australia which provides high-capacity Internet services to Australia's universities, research institutions and related cultural and education organizations. AARNET is actively participating in the TEIN2 project and connects the CSIRO telescopes through a 10 gigabit per second backbone and a dedicated optical network passing over 80 major regional centers throughout Australia.

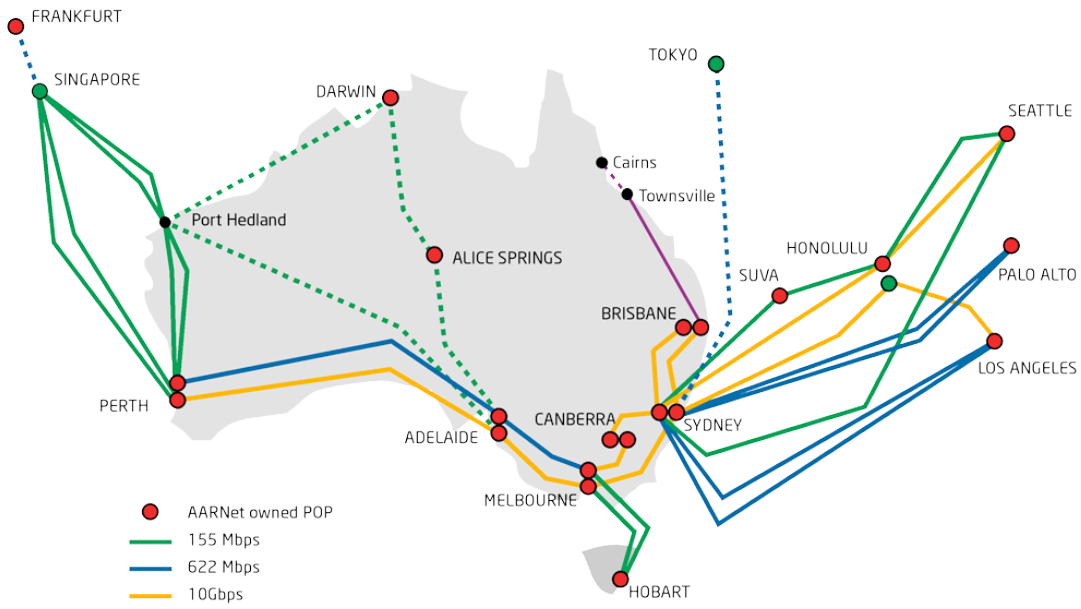


Figure: AARNet Network Map

PSNC

PSNC is responsible for the development and management of PIONIER, the national research network in Poland – which is connected to the GÉANT2 network with the speed of 10Gbit/s. The PIONIER itself is an advanced optical network based on its own fibers, own DWDM transmission equipment and own 10 Gigabit Ethernet communication channels. There is one channel dedicated for connecting the radio telescope at Torun with the GÉANT network.

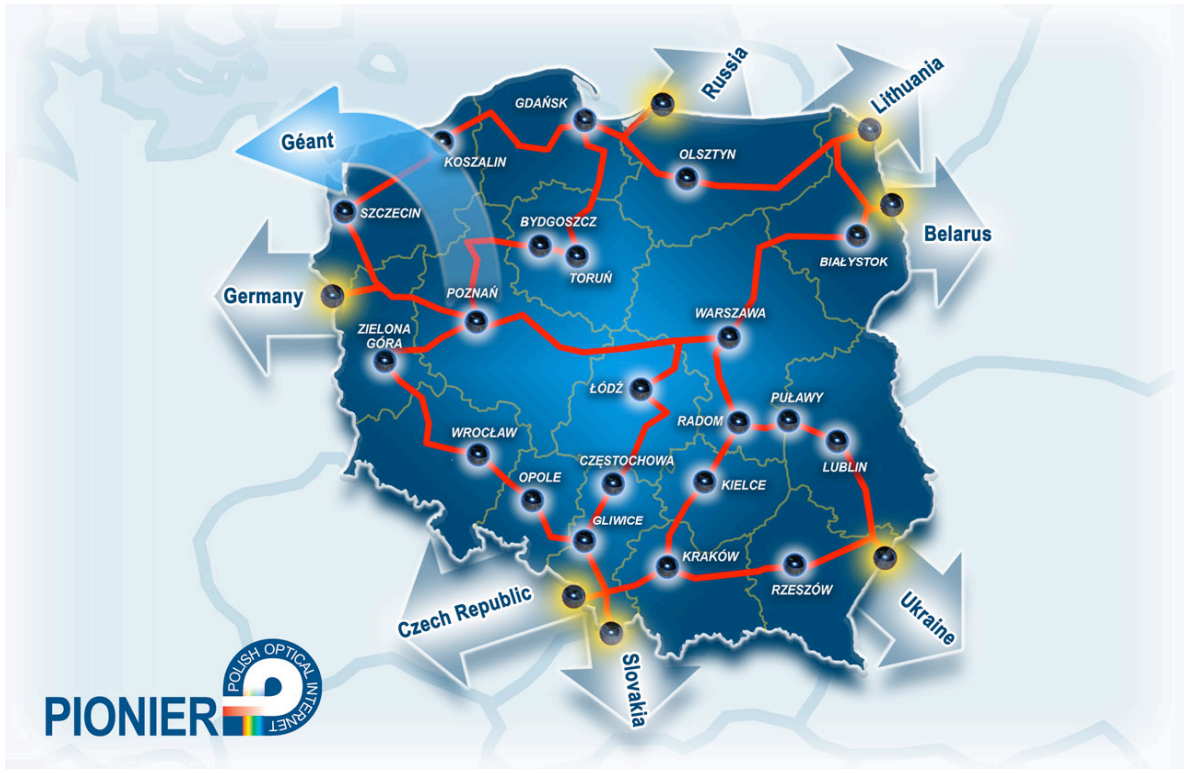


Figure: PIONEER Network Map

Summary of e-VLBI Network Connectivity Progress

At the beginning of the EXPReS project, only a limited number of telescopes had adequate connectivity to national research and education networks and hence to international backbones. In addition, each e-VLBI session required intensive network optimization involving staff from JIVE, the respective telescopes, NRENs and DANTE. Much progress has since been made: the majority of European telescopes are now connected and the network connections operate successfully with a minimum of intervention.

The EVN-NREN interaction, whilst having less routine involvement in e-VLBI sessions, remains important when considering next-generation networking solutions for e-VLBI. Important EXPReS-NREN liaison made possible the success of the 4 Gbps network trials for FABRIC and it is hoped that this work will lead the way to high data-rate e-VBLI in the future.

6th EVN-NREN Meeting - June 24th 2009

This was the final meeting of the EVN-NREN group. To ensure maximum attendance and to widen the scope of the meeting to global as well as European participants, the meeting was held in conjunction with the International e-VLBI Workshop in Madrid in June 2009.

The meeting covered similar ground to previous EVN-NREN sessions: an opportunity for updates on network developments and astronomical progress, together with a round-table discussion on the connectivity status of each telescope. A tour of the Yebes telescope was held that enhanced the social

side of the interaction and helped networkers appreciate the other engineering aspects of the radio-astronomy world.

Visit to Shanghai astronomical Observatory

Representatives of EXPReS NA2 attended the International e-VLBI Workshop in Shanghai, China in June 2008. Presentations were given on the GÉANT and ORIENT projects and on European testing of high data-rate e-VLBI transfers. In addition to the conference dedicated meetings were held between NA2 participants and representatives of the Chinese NRENs, CERNET and CSTnet and with local ShAO staff.

Figure: Richard Hughes-Jones (DANTE) presents results of networking tests between Manchester and Stockholm in the context of EXPReS at the Shanghai e-VLBI Workshop

Connection of Effelsberg

A major long-term objective of the European Radio Astronomy and Networking communities was achieved in 2008 –the successful connection of the Effelsberg Telescope in Germany. The telescope has since regularly taken part in e-VLBI sessions, and, a high-profile launch event inaugurating the link was held on the 19th November 2008. Additional details of the event are available in the NA4 section of this document.

1.4.1.2 NA2 Participating Institutions[5]

The EVN-NREN forum has included contributions from all the partner organizations in EXPReS but also engages with the networking community more generally. Many NRENs who are not EXPReS partners (for example GARR, NORDUnet, DFN, JANET) have made significant contributions to the project at their own expense.

Funding is primarily provided for travel to the EVN-NREN meetings. JIVE is provided a larger proportion to handle costs associated with meeting venue, organization and logistics.

#	Short Name	P3 Claim (EUR)[6]
1	JIVE	4,763.02
2	AARNet	
3	DANTE	
4	PSNC	
5	SURFnet	
6	ASTRON	
7	CNIG-IGN	
8	CSIRO	
9	NRF	
10	INAF	
11	MPIfR	
12	TKK	
13	Cornell	
14	UMK	
15	OSO	
16	ShAO	
17	UdeC	
18	UniMan	
19	VIRAC	
	total	

1.4.1.3 NA2 Deliverables and Milestones Tables

For the final period, NA2's deliverables fall into two categories. The first pertain to the end of project meeting in Madrid. Deliverable 88 and 89 were the meetings and presentations held in Madrid. The

[5] Participation is based on those institutions who have received funding for the activity. The Participating Institution Table assumes the following abbreviations:
P # - Participant Number

[6] Period 3 figures are based the most accurate figures available at the time of writing. Many partners were in the process of their audits and expect changes to these figures. Official figures will be provided as soon as they are available.

last deliverable is the contents for the final report (this document) and the related documents that will be generated from the text.

D#	AD#	Deliverable Description	Lead	Delivery Month		Status[7]
				Planned	Actual	
88	2.05	EVN-NREN meeting No. 3 (with Madrid meeting) (slides for the EVN NREN meeting are posted on the meeting's website, scroll down to Thu 25 June 2009)	DANTE	40	40	4
89	2.06	EVN-NREN representatives present EXPReS networking results at the e-VLBI Science & Technology Workshop (slides for the EVN NREN meeting are posted on the meeting's website)	DANTE	40	40	4
116	2.07	NA2 annual & Final reports	DANTE	42	42	4

1.4.1.4 NA2 Human Resource Overview

Manpower is not claimed under NA2; hence no formal reporting of human resources is given. It is worth noting that many engineers not associated with the project attend the EVN-NREN meetings as well as participate (as needed) in activities such as the GÉANT2 PERT team.

1.4.1.5 NA2 Meetings and Workshops

Date Location	Meeting Title / Subject / Website Address	Number of Attendees
22 June 2009 Madrid, Spain	Final EVN-NREN Meeting, with the End of Project Conference: the 8the International e-VLBI Workshop http://www.oan.es/expres09/	~80

1.4.1.6 NA2 Participation in External Events

NA2 activities have been represented at the following events by members of EXPReS presenting work that was related to or resultant from efforts in NA2.

Date (month)	Event Description / Location
9-11 Apr 2008	The 24th NORDUnet Conference hosted by Funet in Espoo (Helsinki), Finland
19-22 May 2008	TERENA Networking Conference 2008, Bruges, Belgium http://tnc2008.terena.org/
5-7 Mar 2009	Sixth International Workshop on Protocols for FAST Long-Distance Networks The University of Manchester Manchester, UK http://www.hep.man.ac.uk/PFLDnet2008/
8-11 June 2009	TERENA Networking Conference 2009, Malaga, Spain http://tnc2009.terena.org/

[7] The status of the deliverable is tracked on a 0 to 4 scale with 0 indicating no work started and 4 indicating that the deliverable has been accepted by the project office.

	7th International e-VLBI Workshop 16-17 June 2008 Shanghai astronomical Observatory Shanghai, China

1.4.2 NA3- eVSAG

1.4.2.1 NA3 Activity and Status

eVSAG

The eVSAG- e-VLBI Science Advisory Group- has been the primary forum for scientific discussions surrounding e-VLBI since the start of the project. The forum provides a place for users, operators and developers to discuss their different goals and hopefully to find agreement on next steps. The majority of the work of the eVSAG occurred early in the project as the merits and concerns over e-VLBI were discussed in the community. As e-VLBI turned operational, the need for a forum to discuss concerns diminished. As expected, the focus of the activity turned to the end-of-project meeting.

e-VLBI Science Highlights from the Final Period

A most peculiar object: Hanny's Voorwerp

Mike Garrett (ASTRON) lead a project to investigate the recently discovered Hanny's Voorwerp. This is a hot, irregular gas cloud located about 60000 light years from the galaxy IC 2497 which apparently does not contain any heating source. WSRT observations of the neutral hydrogen show that Hanny's Voorwerp is embedded in a gas cloud of 5000 million solar masses, which has an extension stretching out to the position of a galaxy group. Hydrogen spectra reveal the connection between the gas around IC 2497 and the galaxy group. The Voorwerp is part of a much bigger gas cloud, the remnant of an interaction between IC 2497 and a galaxy group. The WSRT radio continuum observations show a source at the centre of IC 2497 with a jet-like extension in the direction of the Voorwerp. Initial e-EVN observations at 1.6 GHz reveal a very small source at the centre of the galaxy, less than 0.1 light years across. This suggests that IC 2497 contains a supermassive black hole at its centre. The plasma jet emanating from the central engine clears a channel through the thick dust and gas that surrounds the black hole, permitting the intense radiation to reach Hanny's Voorwerp. Further e-VLBI observations were carried out by Hayden Rampadarath (ASTRON) et al., which show more detail of the galaxy core at milliarcsecond resolution. These results were presented at the 8th e-VLBI Workshop in Madrid.

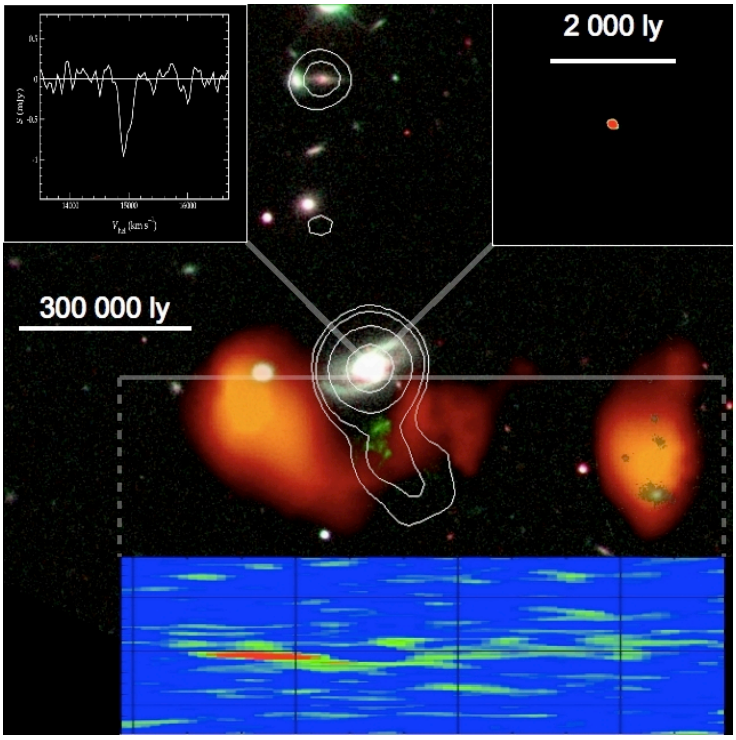


Figure: WSRT radio continuum observations (white contours) of IC 2497 show a jet-like extension in the direction of Hanny's Voorwerp. The e-VLBI observations reveal a very small source at the centre of the galaxy (top-right image). The WSRT neutral hydrogen show that Hanny's Voorwerp is embedded in a gas cloud of 5000 million solar masses (red in the image), which has an extension stretching out to the position of a galaxy group (to the right). Hydrogen spectra reveal the connection between the gas around IC 2497 and the galaxy group (bottom picture).

Cyg X-3 activity cycle revisited

Miqroquasar Cyg X-3 has been very active in the last two years. The triggered e-EVN proposal by Valeriu Tudose (formerly at Univ. Amsterdam, now ASTRON) et al. was activated on 9 April 2008 when the source showed signs of an accretion disk state change in the X-rays. This particular state has never been targeted at milliarcsecond resolution in the radio regime. A single radio component (earlier assumed to be a permanent jet-ISM interaction feature) was detected at a lower emission level than in 2007, consistent with the radio core quenching scenario in the soft X-ray state. The identification of the radio core allowed the group to estimate the proper motion of Cyg X-3. As expected following the state change, Cyg X-3 began a strong radio flare which was observed at three epochs separated by a few days. The group used the e-EVN as well as archival VLBA data to separate the core flux from the occasional jet emission, that allowed a clearer classification of accretion disk states in the system and measure the proper motion of Cyg X-3. These results were presented at the 8th e-VLBI Workshop in Madrid, and a more detailed paper was accepted for publication by MNRAS.

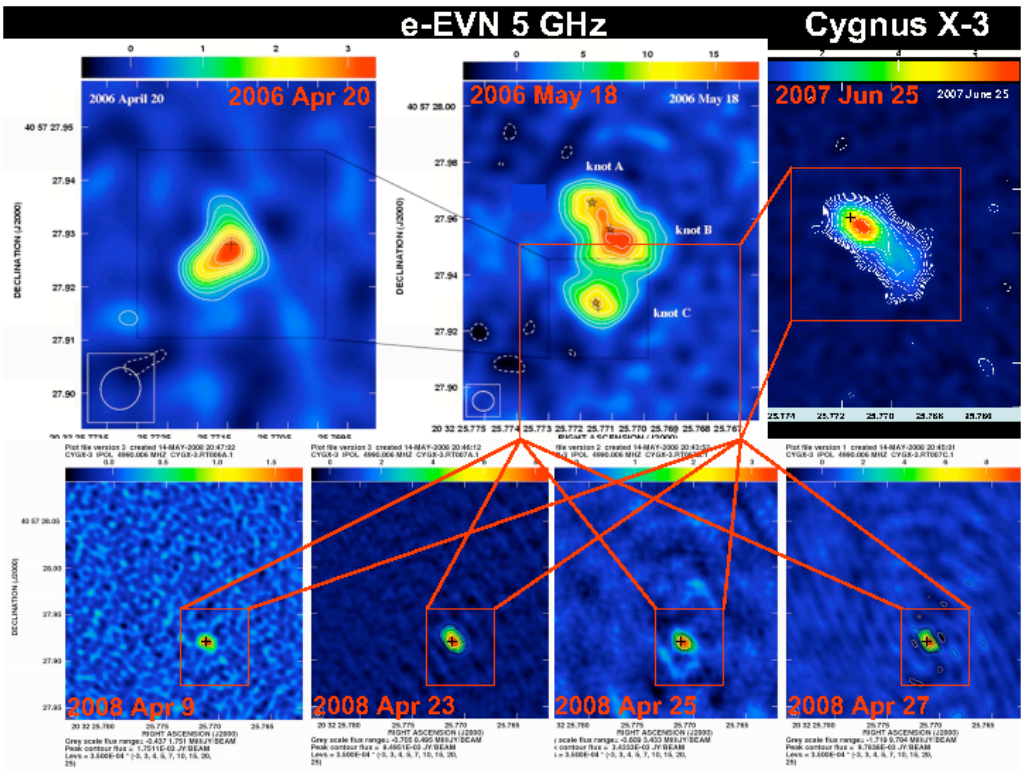


Figure: e-EVN images of Cyg X-3 during different accretion disk states in the period 2006-2008. With these observations the core of the system was cleary identified.

A major outburst in SS433

On 28 October 2008 RATAN-600 reported a major flare in the famous microquasar SS433. Valeriu Tudose (Univ Amsterdam) et al. organised e-EVN monitoring observations of this peculiar event. The first epoch data on 6 November showed three pairs of radio components located symmetrically on both sides of the presumed position of the core of the system, two of which were already resolved. Assuming that the radio ejecta were moving at a rate of about 8 mas/day, the furthest components at about 100 mas from the core were ejected at around 24 October and perhaps the RATAN-600 observations on 28 October caught the aftermath of this event. The two components at about 25 mas from the core could have been ejected around November 3, date which also corresponds to the rebrightening event witnessed by RATAN-600. The results were reported in ATel #1836. Continuing observations with RATAN-600 and the e-EVN (on 13 and 19 November) showed a long-lived flaring activity in the system.

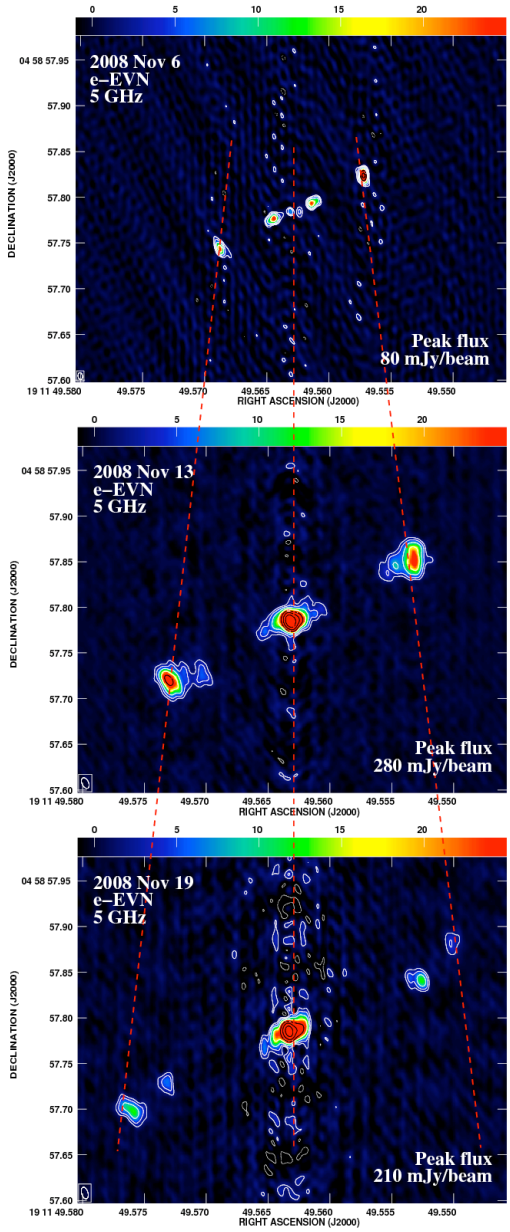


Figure: e-EVN images of a long-lived SS433 flare

Optical and radio interferometry of a hierarhical triple stellar system

Algol is an eclipsing binary stellar system in which the cool K2 IV sub-giant looses matter through Roche-lobe overflow to the more massive B8 V star. A third star is orbiting around the close binary in a long period orbit. The system is the nearest and one of the most active of its kind. A group led by Szilárd Csizmadia (then at Konkoly Observatory, Budapest, Hungary, now at the Institute of Planetary Research, Berlin, Germany) monitored the system with the CHARA optical interferometer, while Zsolt Paragi (JIVE) organised e-EVN observations. The optical interferometer data, with the help of the e-EVN measurements that could resolve the ambiguity in the angle of the ascending node,

provided the most precise information about the geometry of the inner binary system at milliarcsecond resolution. This was the first joint application of these two unique, complementary techniques. A promising future application will be in the field of star-formation theory of hierarchic triple stellar systems. A paper describing the results was accepted for publication by the Astrophysical Journal.

An AGN in the heart of a suspected "dark lens" galaxy

Recently an optical arc was discovered near a faint radio source, J1218+2953, which looks like a gravitationally lensed image of a galaxy. While the radio source may belong to the lensing galaxy, it is not detected in deep optical and infrared images. It was suggested by Ryan et al. (2008, ApJ 688, 43) that the object may be either an extremely obscured system, or a galaxy completely dominated by dark matter.

Sandor Frey (FOMI SGO, Penc, Hungary) et al. carried out a series of e-EVN observations of the radio source at 1.6 GHz and 5 GHz in 2009. The source was initially detected on 23 January 2009. It was resolved into two components separated by about 0.5 arcseconds. This initial detection allowed for more detailed follow-up observations. The image at 1.6 GHz reveals a rich and complex structure in a nearly symmetrical "inverted S" shape, spanning almost 0.7 arcseconds. Comparison of the flux density in this image and the total flux density measured by the WSRT reveals that the radio source itself is almost completely revealed by the e-EVN. These values were close enough to exclude the possibility that the optical arc is sufficiently strong in the radio. Therefore both the arc and the radio source J1218+2953 cannot be gravitationally lensed images of the same background object. A more likely scenario is that J1218+2953 is a young, recently triggered and heavily obscured AGN. It grows in a dense interstellar medium which might cause the observed two-sided bent radio jet structure. This makes the "dark lens" interpretation unlikely. More details on the observations of this interesting object will be published in the proceedings of the 8th International e-VLBI Workshop, held in Madrid.

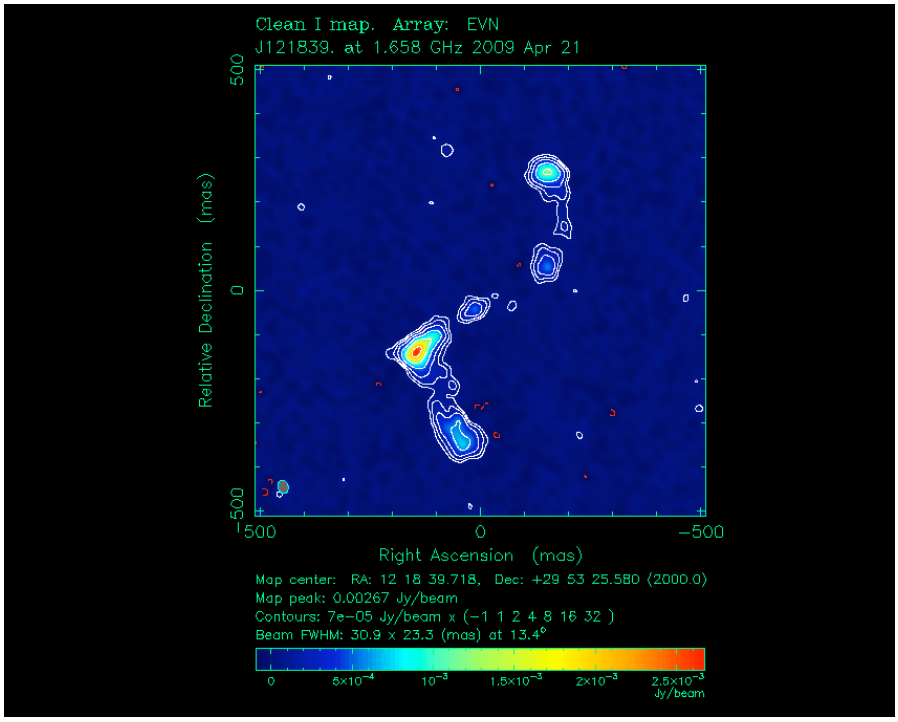


Figure: The naturally weighted 1.6-GHz e-EVN image of J1218+2953. There is evidence for AGN activity in a dense environment, that supports the heavily obscured galaxy scenario

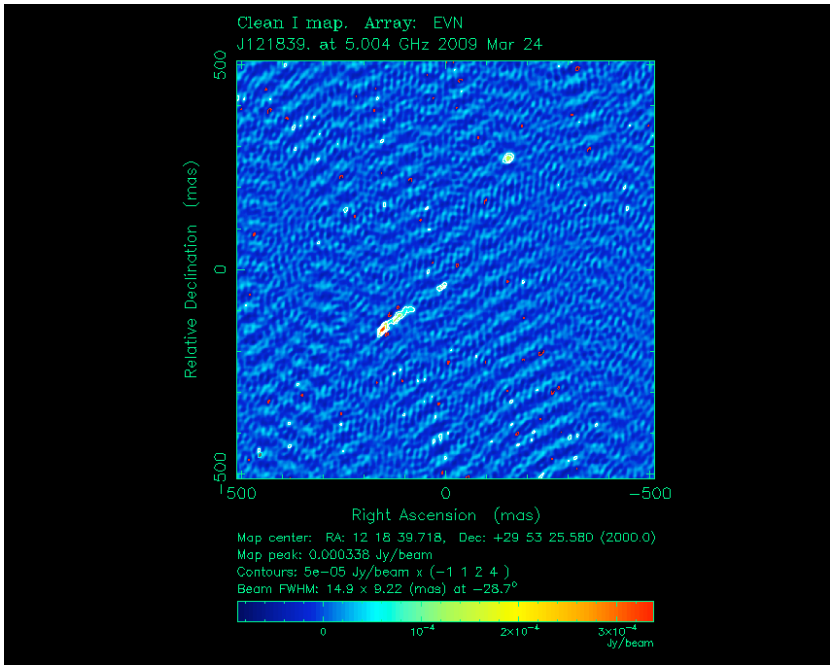


Figure: The naturally weighted 5-GHz e-EVN image. The spectra of the components (some of them are

resolved out here) are steep, typical of young radio sources.

Arp 299: a supernova factory

The central regions of many Luminous Infra-red Galaxies are known to host intense bursts of massive star formation, resulting in copious explosions of supernovae. However, the dust-enshrouded ambients where those supernovae explode prevent their detection at optical and near-infrared wavelengths, and the only way to discover them is by means of radio observations. Miguel Angel Perez-Torres (IAA, Granada, Spain) et al. observed the central region of the Luminous Infrared Galaxy Arp 299, using the e-EVN at 5 GHz. The images obtained on 8 April 2008 and 5 December 2008 reveal the presence of 25 compact radio emitting sources, in the central 500 light years of the galaxy. The only viable explanation for many of the newly discovered sources is that they correspond to recently exploded core-collapse supernovae, and the rest are most likely super star clusters and supernova remnants. This rules out starburst scenarios with constant star forming rates of massive stars in Arp 299, and yields support for either recent (few million years), instantaneous starbursts or, alternatively, a top-heavy initial mass function of the stars in Arp 299. These results were presented at the 8th e-VLBI Workshop in Madrid.

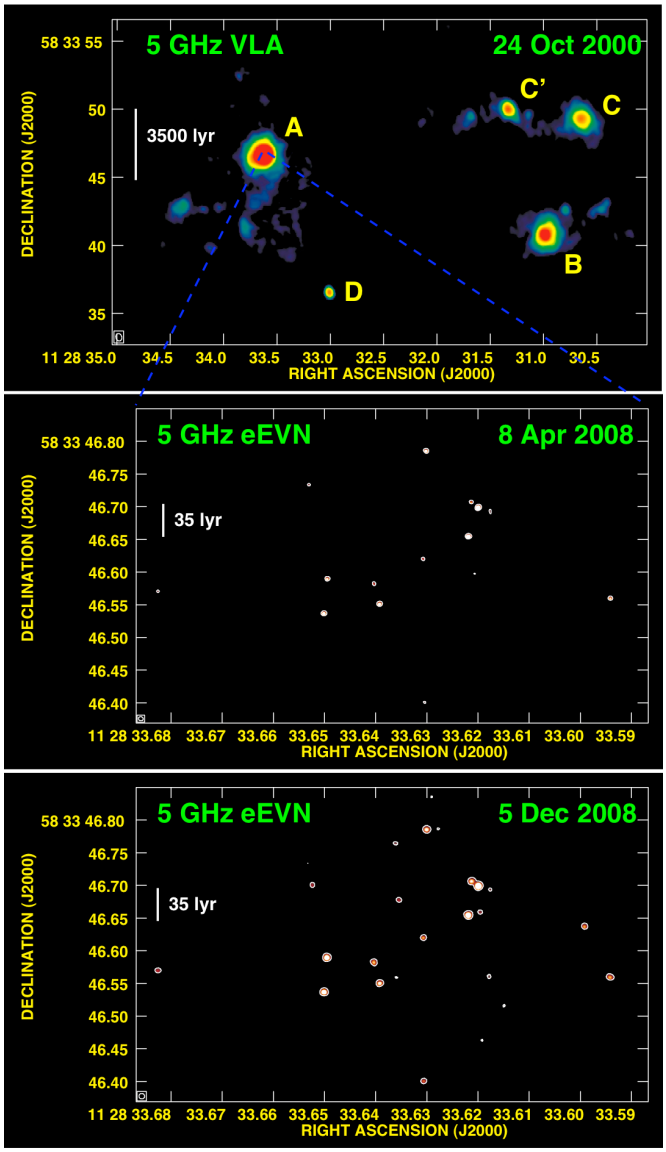


Figure: The top image shows 5 GHz VLA archival observations of Arp 299 on 24 October 2000, displaying the four brightest knots of radio emission in this merging galaxy. Middle and bottom: 5 GHz e-EVN observations of the central 500 light years of the Luminous Infrared galaxy Arp 299 on 8 April 2008 and 5 December 2008. The appearance and disappearance of several (at least eight) new compact sources between April and December 2008 is evident. The only viable explanation for those components is that we are witnessing the fading away of several radio supernovae, along with the rising phase of radio emission of core-collapse SNe that exploded very recently. The rest of the compact sources are most likely either supernova remnants, or super star clusters. North is up and East is left in the image.

End of Project Meeting: Science and Technology of Long Baseline Real-Time Interferometry

The End of Project Science Meeting, formally titled "The Science and technology of Long Baseline Real-Time Interferometry" <http://www.oan.es/expres09>, was the primary effort for NA3 for the final period of the project. The week long meeting served to highlight not only the science results made possible by EXPReS but also the technological progress that was completed during the process. The meeting was split into two halves: the first half focused on ASTRONomy science, the second half of the meeting focused on technology (a umbrella term covering networking, computation, software development and protocol design/implementation). Integrated into the schedule were related EXPReS Meetings (e.g., EVN-NREN) as well as official side meetings taking advantage of the concentration of attendees. In total, over 80 different people attended one of the five days of the workshop (see photographs below).

The meeting was divided into eleven sessions (see list below) and over 40 talks are posted online with slides. The full agenda is available on the meeting's website In addition, proceedings from the meeting are currently in preparation and should be published in the early November timeframe. The proceedings will be made available online via Proceedings of Science <http://pos.sissa.it/>.

Table: Session number, description and Chair from the End of Project Meeting

1	Introductory Talks – Jesús Gómez González (IGN)
2	Transients I - Zsolt Paragi (JIVE)
3	Non-transient e-VLBI Observations - Chris Phillips (CSIRO/ATNF)
4	Geodesy and Astrometry - Huib van Langevelde (JIVE)
5	Transients II - James Miller-Jones (NRAO)
6	Joint Science/technical session - regional and instrument reports
7	NREN Meeting (Chair: John Chevers - DANTE)
8	e-VLBI Techniques (Chair: Arpad Szomoru - JIVE)
9	VDIF Session (Chair: Alan Whitney – MIT-Haystack RAO)
10	Software and Distributed Correlation (Chair: Richard Hughes-Jones - DANTE)
11	The Future of Networks and VLBI Science (Chair: Ralph Spencer - JBCA/ Manchester U)

Figure: Photographs from the e-VLBI Workshop, Madrid, Spain

Remote participation in the e-VLBI

The e-VLBI meeting was also made available to remote participants via EVO, the online videoconferencing system <http://evo.caltech.edu/>. The availability of the videoconferencing option was not shared widely as it was somewhat experimental, but it did allow several people to view the conference. Over the week long conference, the Project Manager informally counted 8 remote viewers from both Europe, the United States and Australia log into the system. A desktop capture from one of the days is shown below.

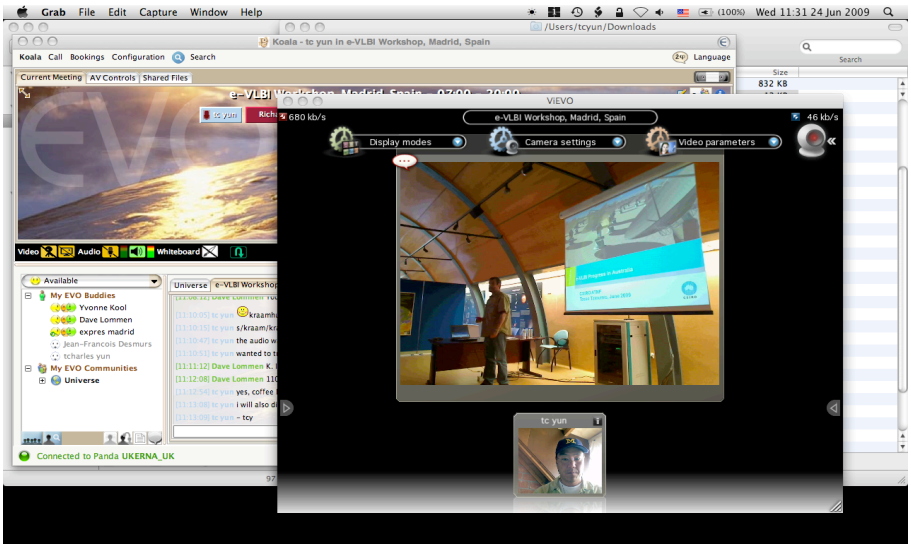


Figure: Desktop capture of the EVO videoconferencing system during the Wednesday session of the e-VLBI Workshop.

e-VSAG Meeting

The e-VSAG met in Madrid, Spain in conjunction with the End of Project Meeting. The closed meeting was advertised on the agenda and held on Monday 22 June. No new actionable items were identified as the project was coming to a close.

1.4.2.2 NA3 Participating Institutions[8]

Since the subject matter of NA3 is the (principally astronomical) end-user science of EXPReS, the participants in this network activity are the radio astronomical institutes within EXPReS. The table below lists the participants and summarizes their claims for this activity in the final period as well as a total across the lifetime of the project. As noted earlier, the main activity for this period was the end of project meeting. JIVE took the primary burden of organization and coordination and registered most of the spending and effort.

[8] Participation is based on those institutions who have received funding for the activity. The Participating Institution Table assumes the following abbreviations:
P # - Participant Number

#	Short Name	P3 Claim (EUR)[9]
1	JIVE	67,612.53
6	ASTRON	
7	CNIG-IGN	
8	CSIRO	
9	NRF	
10	INAF	
11	MPIfR	
12	TKK	
13	Cornell	
14	UMK	
15	OSO	
16	ShAO	
17	UdeC	
18	UniMan	
19	VIRAC	
	total	67,612.53

1.4.2.3 NA3 Deliverables and Milestones Tables

The primary deliverable for the period was the end of project e-VLBI Workshop held in Madrid. The planning for this meeting involved a great deal of effort from the activity leader, project office and host location. The eVSAG meeting was held in conjunction with the workshop, along with several other meetings. At the time that this report was being prepared, the proceedings were being collected and readied for publication; by the time this report is accepted, the proceedings should be completed.

D#	AD#	Deliverable Description	Lead	Delivery Month		Status[10]
				Planned	Actual	
91	3.03	eVSAG meeting No. 3	OSO	40	40	4
94	3.04	e-VLBI Workshop to be held in Madrid (workshop website)	OSO	40	40	4
107	3.05	Publication of e-VLBI Workshop proceedings (POS online proceedings)	JIVE	42	42	4

[9] Period 3 figures are based the most accurate figures available at the time of writing. Many partners were in the process of their audits and expect changes to these figures. Official figures will be provided as soon as they are available.

[10] The status of the deliverable is tracked on a 0 to 4 scale with 0 indicating no work started and 4 indicating that the deliverable has been accepted by the project office.

1.4.2.4 NA3 Human Resource Overview

Formally, NA3 does not have a human resource component. However, it is important to note the considerable effort provided in support of the activity by the activity leader John Conway. Conway provided time not only for the day to day support of the activity, but also the large time investment needed to organize the end of project e-VLBI Workshop in Madrid. Zsolt Paragi, scientist at JIVE, also supports the science activities of EXPReS through hands on support of scientists making observations as well as through his position working with the EVN in crearting the e-VLBI schedules.

1.4.2.5 NA3 Meetings and Workshops

NA3 sponsored the end-of-project e-VLBI workshop in Madrid as the primary activity of the final period. Details of this week long workshop are described earlier in this section.

Date/Location	Meeting Title / Subject / Website Address	# Attendees
22 June 2009 Madrid, Spain	End of Project Conference: the 8the International e-VLBI Workshop Capstone meeting with presentations on ASTRONomy science and technology enabled by and related to EXPReS http://www.oan.es/expres09/	~80

1.4.2.6 NA3 Participation in External Events

NA3 was not involved directly in any external events. Individuals participated on behalf of EXPReS via other activities and their home institutions.

1.4.3 NA4- e-VLBI Outreach, Dissemination and Communications

1.4.1.3 NA4 Activity and Status

Press releases and Media Mentions

EXPReS is not purely an astronomical activity. In order that the ICT and astronomical aspects of the project are addressed in an appropriate way throughout the infrastructures which join the telescopes, EXPReS includes among its partners four networking organisations.

EXPReS and its participating institutes issued 20 press releases recognizing significant milestones and activities during period 3. These included:

- the first successful e-VLBI observations with Effelsberg, Hartebeesthoek and TIGO telescopes;
- the first e-VLBI observation with telescopes in Africa, Europe North America and South America;
- inauguration of the Effelsberg telescope into the e-EVN;
- a marathon e-VLBI observation with 17 telescopes demonstrated live at the International Year of Astronomy opening ceremony; and
- an e-VLBI demonstration and webcast as part of the 100 Hours of Astronomy.

These press releases generated significant media interest, resulting in approximately 50 web postings, newspaper articles and other media mentions, including *NewScientist*, *Slashdot*, *Sky & Telescope* and *SpaceDaily*. Press releases and links to media mentions are available on the EXPReS web site at http://www.expres-eu.org/news.html.

EuroNews

In April 2008, EXPReS was approached by the EuroNews television channel to participate in an episode of their *Futuris* program about next-generation telescopes. A production team visited JIVE and filmed segments with EXPReS coordinator Huib van Langevelde, head of R&D Arpad Szomoru, project manager T. Charles Yun, support scientist Zsolt Paragi and correlator operator Martin Leeuwinga in the JIVE control room and at the Westerbork Synthesis Telescope Array. The program, translated into seven languages, aired 20 times in May 2008. It is also available online at http://www.youtube.com/watch?v=lfO-85RDhFk.

Display

The EXPReS display travelled to a number of meetings and outreach events during period 3, including:

- 19-22 May 2008 – TERENA Networking Conference, Bruges, Belgium (*see photo: below left*)
- 16-17 June 2008 - 7th International e-VLBI Workshop, Shanghai astronomical Observatory, Shanghai, China
- 5-8 September 2008 - MPIfR Open Day, Bonn, Germany
- 15 September - 3 October 2008 - 9th EVN Symposium, Bologna, Italy

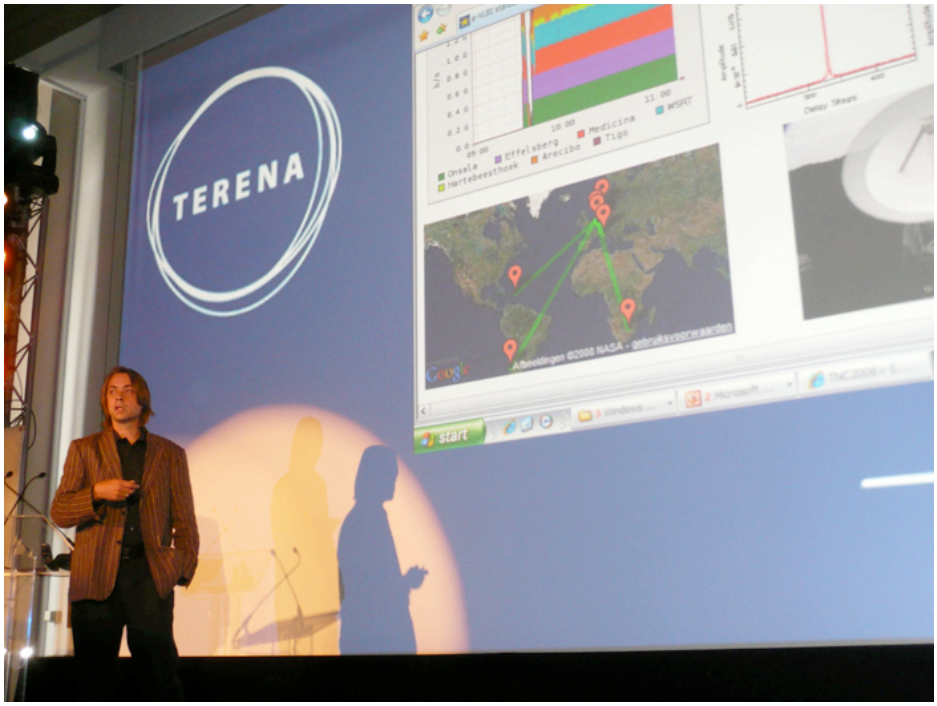
- 19 October 2008 - ASTRON/JIVE Open Day, Dwingeloo, the Netherlands (*see photo: below right*)
- 19 November 2008 – Effelsberg e-VLBI inauguration, Effelsberg, Germany
- 20-23 April 2009 - European Week of Astronomy & Space Science, Hertfordshire, UK
- 22-26 June 2009 - The 8th International e-VLBI Workshop, Madrid, Spain

Above left: Following the TNC2008 Closing Plentary by Huib van Langevelde, attendees talk with EXPReS representatives about the live e-VLBI observation. Above right: JIVE Software Engineer Mark Kettenis talks with a visitor during the ASTRON/JIVE Open Day.

Demonstrations

EXPReS conducted a number of live e-VLBI demonstrations during period 3:

- In May 2008, EXPReS conducted the first e-VLBI observation with Hartebeesthoek telescope in South Africa. A top delegation from the EU was at Hartebeesthoek to observe this first experiment, including Jose Manuel Maria Rodriguez, Director-General of DG-Research, and Antti Peltomaki, Deputy Director-General of DG-INFSO.
- In May 2008, EXPReS conducted the first ever e-VLBI observation with telescopes in Africa, Europe, North America and South America, and demonstrated live to approximately 400 networking professionals as part of the Closing Plenary at TERENA Networking Conference 2008 in Bruges, Belgium (*see photo: below*). A video of the Closing Plenary is available at http://tnc2008.terena.org/media/archive.php?stream=36.



Above: As the Closing Plenary at TNC2008, EXPReS Coordinator Huib van Langevelde presents real-time images from the e-VLBI observation demo.

- In November 2008, a Target of Opportunity e-VLBI observation was demonstrated live at a reception inaugurating the 100-m radio telescope at Effelsberg into the e-EVN. Attendees included representatives from the EC, German press, MPIfR and JIVE.
- In January 2009, EXPReS conducted a marathon e-VLBI observation of nearly 33 hours using 17 telescopes around the world. This observation was demonstrated live at the Opening Ceremony for the International Year of Astronomy in Paris. The event had over 800 enthusiastic attendees, including Nobel Prize winners, government officials, professional astronomers and aspiring young scientists from over 100 countries, many of whom visited the EXPReS exhibit to talk with representatives about the observation, e-VLBI technique and the EXPReS project, and to try e-VLBI for themselves using an online Virtual Radio Interferometer. (See IYA2009 Web Site below.)
- In April 2009, a press event was hosted by SURFnet and JIVE, which included a live e-VLBI demonstration to members of the Dutch press. This resulted in articles in popular newspapers De Telegraaf and NRC Handelsblad, and a radio piece from RTV Drenthe.

Effelsberg Inauguration

In November 2008, EXPReS and MPIfR hosted a reception to inaugurate the 100-m radio telescope at Effelsberg into the e-EVN. Approximately 40 attendees, including representatives from the EC, MPIfR and JIVE, as well as members of the German press, gathered to hear remarks about the significant inclusion of such a large and sensitive instrument into regular e-VLBI operations and to take a tour of the telescope. A press release regarding the event is available here: http://www.expres-eu.org/Effelsberg_inauguration.html.

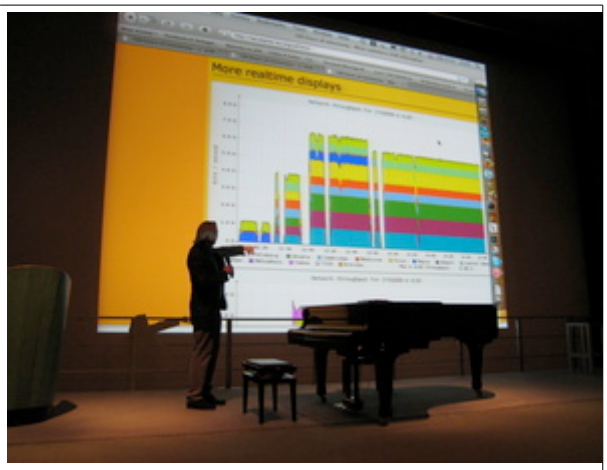
Above left: Jean-Luc Dorel comments on the significance of including the Effelsberg telescope in e-VLBI capabilities. Above right: inauguration attendees tour the 100-m Effelsberg telescope.

International Year of Astronomy

2009 marks the International Year of Astronomy (IYA2009), as organized by UNESCO and the International astronomical Union. EXPReS has already participated IYA2009 in numerous ways during period 3:

- In January 2009, in conjunction with the IYA2009 Opening Ceremony in Paris, EXPReS participated in a marathon e-VLBI observation of nearly 33 consecutive hours involving 17 telescopes around the world. EXPReS set up an exhibit at the Opening Ceremony to demonstrate the observation and showcase e-VLBI as a new astronomical technique to over 800 attendees. The exhibit was visited by hundreds of enthusiastic and inquisitive attendees, who asked a broad range of questions about radio astronomy and e-VLBI and who were able to try a Virtual Radio Interferometer for themselves. (See IYA2009 Web Site below.) Press releases, media mentions, video and photos from the event can be found on the EXPReS wiki: http://www.jive.nl/dokuwiki/doku.php/expres:sa1:iya2009demo. (See photo: below left.)
- "100 Hours of Astronomy", a cornerstone project of IYA2009, took place 2-5 April 2008. EXPReS participated with two e-VLBI observations on 3 and 5 April, a live segment during the "Around the World in 80 Telescopes" 24-hour webcast marathon, and lecture and demonstration by EXPReS Coordinator Huib van Langevelde during the "Weekend of the Stars" event at the NEMO science centre in Amsterdam 5 April (see photo: below right). The 20-minute webcast can be viewed here: http://www.ustream.tv/recorded/1336875.

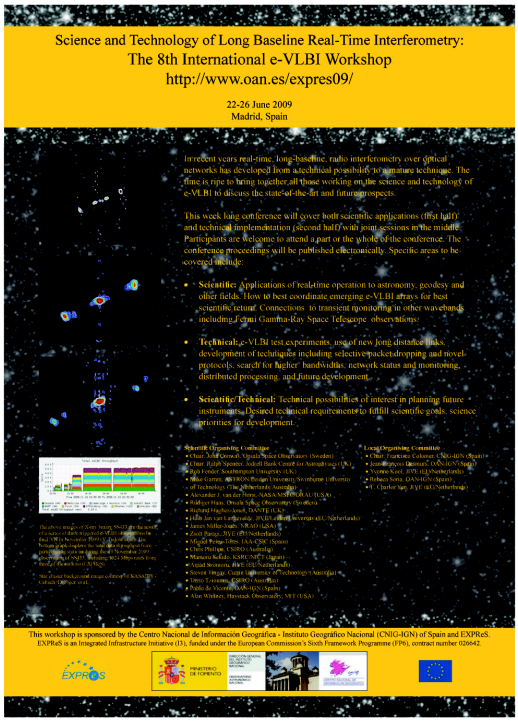
- IYA2009 Web site – A web site devoted to EXPReS and EVN outreach activities for the International Year of Astronomy was set up at http://iya.expres-eu.org/. Written for non-astronomers, the site provides basic information about how radio astronomy, VLBI and e-VLBI work, and information and live updates about e-VLBI observations occurring as part of IYA2009. The site also includes a Virtual Radio Interferometer (http://192.42.120.99/vri.jnlp) which users can play with to see how different factors such as array size, observation time and declination affect the astronomical image produced during an observation.



Above left: attendees of the International Year of Astronomy Opening Ceremony stop by the EXPReS exhibit to learn more about e-VLBI and the marathon observation being demonstrated. Above right: EXPReS Coordinator Huib van Langevelde demonstrates e-VLBI at "Weekend of the Stars" at the NEMO science centre in Amsterdam.

Madrid workshop poster and advertising

An A2 poster advertising "Science and Technology of Long Baseline Real-Time Interferometry: The 8th International e-VLBI Workshop" was designed, printed and distributed to astronomy institutes and university departments in January 2009. A full-page, black & white ad was also placed in the journal Astronomy & Astrophysics.



Science and Technology of Long Baseline Real-Time Interferometry:

The 8th International e-VLBI Workshop

22-26 June 2009 - Madrid, Spain
www.oan.es/expres09/

In recent years real-time, long-baseline, radio interferometry over optical networks has developed from a technical possibility to a mature technique. The time is ripe to bring together all those working on the science and technology of e-VLBI to discuss the state-of-the-art and future prospects.

This week-long conference will cover both scientific applications (first half) and technical implementation (second half) with joint sessions in the middle. Participants are welcome to attend a part or the whole of the conference. The conference proceedings will be published electronically. Specific areas to be covered include:

- **Scientific:** Applications of real-time operation to astronomy, geodesy and other fields. How to best coordinate emerging e-VLBI arrays for best scientific return. Connections to transient monitoring in other wavebands including Fermi Gamma-Ray Space Telescope observations.
- **Technical:** e-VLBI test experiments, use of new long distance links, development of techniques including selective packet dropping and novel protocols, search for higher bandwidths, network status and monitoring, distributed processing, and future development.
- **Scientific/Technical:** Technical possibilities of interest in planning future instruments. Desired technical requirements to fulfill scientific goals, science priorities for development.

Scientific Organising Committee

- Chair: John Conway, Onsala Space Observatory (Sweden)
- Chair: Ralph Spencer, Jodrell Bank Centre for Astrophysics (UK)
- Rob Fender, Southampton University (UK)
- Mike Garrett, ASTRON/Leiden University/Swinburne University of Technology (The Netherlands/Australia)
- Alexander J. van der Horst, NASA/MSFC/ORAU (USA)
- Rüdiger Haas, Onsala Space Observatory (Sweden)
- Richard Hughes-Jones, DANTE (UK)
- Huib Jan van Langevelde, JIVE/Leiden University (EU/Netherlands)
- James Miller-Jones, NRAO (USA)
- Zsolt Paragi, JIVE (EU/Netherlands)
- Miguel Perez-Tores, IAA-CSIC (Spain)
- Chris Phillips, CSIRO (Australia)
- Mamoru Sekido, KSRC/NICT (Japan)
- Arpad Szomoru, JIVE (EU/Netherlands)
- Steven Tingay, Curtin University of Technology (Australia)
- Tasso Tzioumis, CSIRO (Australia)
- Pablo de Vicente, OAN-IGN (Spain)
- Alan Whitney, Haystack Observatory, MIT (USA)

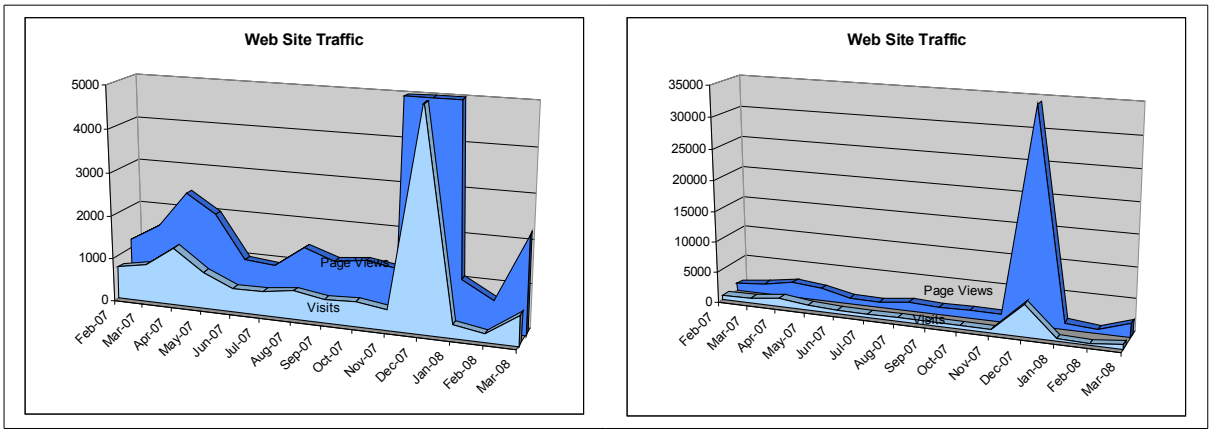
Local Organising Committee

- Chair: Francisco Colomer, CNIG-IGN (Spain)
- Jean-François Desmurs, OAN-IGN (Spain)
- Yvonne Kool, JIVE (EU/Netherlands)
- Rebeca Soria, OAN-IGN (Spain)
- T. Charles Yun, JIVE (EU/Netherlands)

This workshop is sponsored by the Centro Nacional de Información Geográfica - Instituto Geográfico Nacional (CNIG-IGN) of Spain and EXPReS. EXPReS is an Integrated Infrastructure Initiative (I3), funded under the European Commission's Sixth Framework Programme (FP6), contract number 026642.

Web Site and wiki usage

The EXPReS public web site <http://www.expres-eu.org> and wiki <http://www.jive.nl/dokuwiki/doku.php?id=expres:expres> continue to be updated with events, e-VLBI test results, news, media mentions and outreach support materials. There was a tremendous spike in traffic to the public web site in January 2009 with the IYA2009 Opening Ceremony demonstration.



Presentations and Participation

EXPReS project members attended and presented at numerous meetings and events in period 3. Presentations from these events are listed later in this report and posted on the EXPReS web site <http://www.expres-eu.org/papers.html>. Additional presentations and papers are listed on the wiki in the sections for each activity.

ASTRON/JIVE Daily Image

The ASTRON/JIVE Daily Image is an "Astronomy Picture of the Day"-like web page for ASTRON and JIVE <http://www.astron.nl/dailyimage/>. In addition to "publication ready" astrophysical images, it also features photos on a wide range of topics covering all that happens at ASTRON and JIVE. There were a number of EXPReS-related submissions to the Daily Image in period 3, including:

- 8 April 2008 – Effelsberg joins the e-EVN
- 11 April 2008 - "EXPReS sluit je aan" (marking the longest uninterrupted correlation during the e-VLBI science observations on 8-9 April)
- 30 May 2008 – Live demo of e-VLBI from four continents
- 8 July 2008 – 7th international e-VLBI workshop
- 10 July 2008 – "All the colors of the rainbow, and then some" (use of various new fibre optic modules in the connection between Westerbork and Dwingeloo to send data at 1024 Gbps)
- 11 July 2008 - e-EVN detection of the candidate radio counterpart of a gamma-ray source
- 29 October 2008 – Big is Beautiful: e-VLBI detection with and without Effelsberg
- 28 November 2009 - The ultimate e-EVN milestone: 1 Gbps observations
- 3 February 2009 – e-VLBI kick-off at the IYA 2009 a great success
- 3 April 2009 – 100 Hours of Astronomy
- 1 July 2009 - The 8th International e-VLBI Workshop

1.4.3.2 NA4 Participating Institutions[11]

NA4 activity takes place at JIVE with the employment of the EXPReS Public Outreach Officer, and production of publicity materials.

#	Short Name	P3 Claim (EUR)[12][13]
1	JIVE	55,558.95
	total	55,558.95

1.4.3.3 NA4 Deliverables and Milestones Tables

D#	AD#	Deliverable Description	Lead	Delivery Month		Status[14]
				Planned	Actual	
83	NA 4.06	e-VLBI Demonstration and attendance at Network events: APAN demonstration, presentations, IYA 2009 (main site, EXPReS sub-page, press release, images and links).	JIVE	24	18	x
117	NA 4.07	e-VLBI Demonstration and attendance at network events	JIVE	36	30	X

1.4.3.4 NA4 Human Resource Overview

The EXPReS Public Outreach Officer is a half-time position located at JIVE. This person is responsible for creating and maintaining the EXPReS web site and the web-based management tools required to meet NA4 objectives. This person also writes press releases and generates all promotional material.

1.4.3.5 NA4 Meetings and Workshops

NA4 did not sponsor any events directly, but participated in the organization, publicity and follow up of all events sponsored under EXPReS. The details of those meetings can be found in the Meetings and Workshop sections of the respective activities in this report.

[11] Participation is based on those institutions who have received funding for the activity. The Participating Institution Table assumes the following abbreviations:
P # - Participant Number
[12] Period 3 figures are based the most accurate figures available at the time of writing. Many partners were in the process of their audits and expect changes to these figures. Official figures will be provided as soon as they are available.
[13] Note that NA4 costs for return postage were registered by the partner sending the display. Those costs are not reflected in this table, but are shown properly in the Form C. Specifically, this applies to TKK/Metsahovi.
[14] The status of the deliverable is tracked on a 0 to 4 scale with 0 indicating no work started and 4 indicating that the deliverable has been accepted by the project office. An "x" indicates that the activity was deemed ongoing, and continued beyond the original delivery date.

1.4.3.6 NA4 Participation in External Events

Kristine Yun, EXPReS Public Outreach Officer, attended three external events in Year 3:

- TERENA Networking Conference 2008, Bruges, 19-22 May 2008
- International Year of Astronomy Opening Ceremony, Paris, 15-16 January 2009
- Weekend of the Stars, Amsterdam, 5 April 2009

Date (month)	Event Description / Location
19-22 May 2008	TERENA Networking Conference 2008, Bruges, Belgium
15-16 Jan 2009	International Year of Astronomy Opening Ceremony, Paris, France
04/05/09	Weekend of the Stars, Amsterdam, the Netherlands

1.5 SA1- Production e-VLBI Service

1.5.1 SA1 Activity and Status

Introduction

The last 18 months of EXPReS saw a flurry of activity in SA1. With the main problems of long-haul high data-rate transfers solved in the second year of the project, new telescopes on all continents joined the e-EVN. Through a number of high-profile demonstrations, showcasing e-VLBI during the main events of the International Year of Astronomy, global ad-hoc real-time arrays were created that were later requested and used for regular scientific observations.

The difficulties of combining different telescopes with different data acquisition systems in real-time inspired a drive towards data format standardization. At the international e-VLBI workshop in 2008 in Shanghai a working group was elected, with representatives from the major VLBI communities, and instructed to create a new, general data format. At the e-VLBI workshop in Madrid, one year later, this team presented the community with the VDIF data format, which was unanimously approved. Versatile and complete, this standard will be implemented in existing VLBI systems, but also in all DAS systems currently being developed.

Methods of fitting data rates to available bandwidth were improved and new real-time displaying capabilities were further developed. 512 Mbps became the production data rate, even for remote telescopes such as the Sheshan telescope near Shanghai and the Arecibo radio telescope in Puerto Rico. The largest fully steerable dish of the EVN, the Effelsberg radio telescope, came online, resulting in a great improvement in sensitivity of the e-EVN.

Several European stations upgraded their connectivity to 10 Gbps, in some cases through collaborations with the international E-LOFAR effort, allowing for the first time full 1024 Mbps e-VLBI. At the correlator, all Mark5 units were outfitted with 10 Gbps equipment.

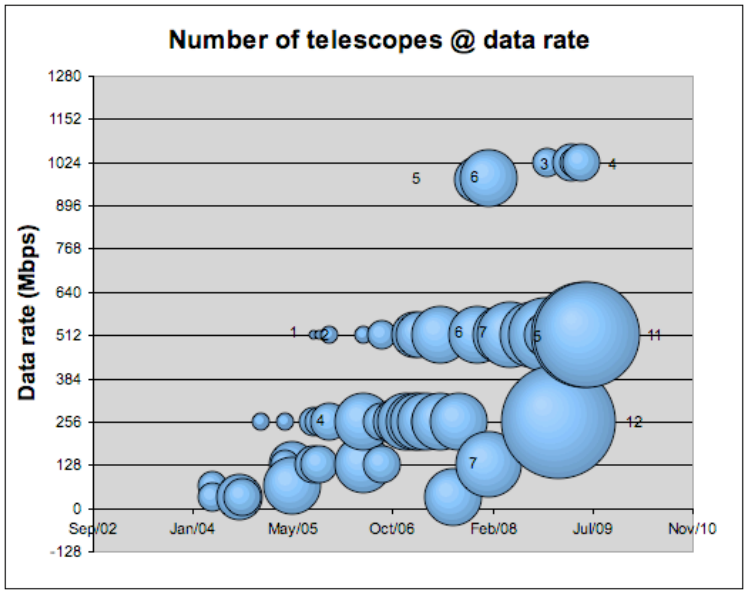


Figure: Data rate per telescope per e-VLBI session, with the size of the bubbles indicating the number of participating telescopes.

Finally, multiple Merlin telescopes were connected in real-time to the EVN correlator by using multicast over the two existing links to Jodrell Bank, adding many short baselines and considerably improving the sensitivity of the array to larger structures.

Figure: Aggregate data rate into JIVE.

e-VLBI tests and science runs

Regular e-VLBI sessions continued as in previous years, and in addition, several Target-of-Opportunity observations were requested and granted. More e-VLBI proposals were submitted than in previous years, a sign that the community at large is beginning to appreciate the potential of this technique. The vastly improved sensitivity and the inclusion of long baselines no doubt played a role as well.

24-hour e-VLBI sessions, scheduled at roughly 6-weekly intervals, continued throughout the last 18 months of the project. As before, these runs were divided into test and science parts, depending on proposal pressure and the need for test time. In addition to these scheduled runs, many off-line tests were conducted.

Details of individual runs:

On **8-9 April 2008**, the first production 512 Mbps e-EVN observations took place. Participating telescopes were Cambridge, Jodrell Bank, Medicina, Onsala, Torun, and the Westerbork phased array. Two science projects were observed: one normal non-triggered and one triggered.

The correlation job on the first project ran for nearly 13 hours, the longest uninterrupted correlation job at JIVE, including disk operations. The first 45 minutes of the second project were lost because of a control computer problem unrelated to e-VLBI, and another hour of Medicina data was lost due to a problem with a Mark5A. In spite of this, the run went very well and produced about 8.5 hours of data on the X-ray binary Cyg X-3. The preliminary results of this run were published in The Astronomer's Telegram #1476 <http://www.astronomerstelegram.org/?read=1476>.

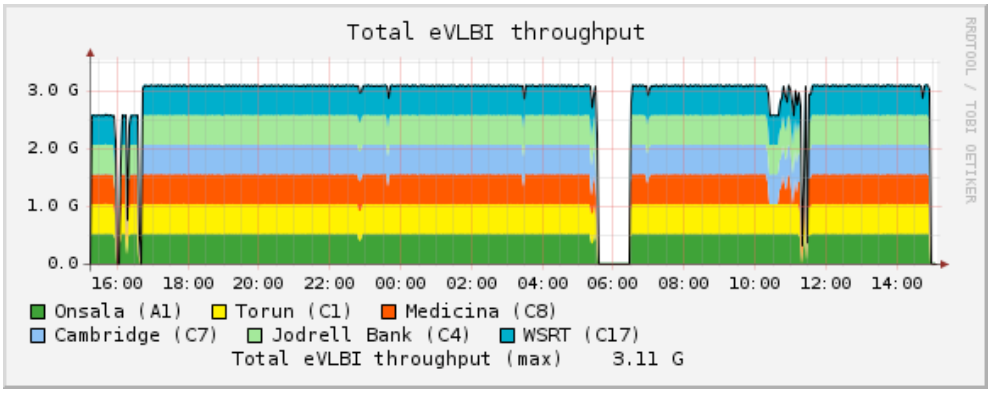


Figure: Throughput plot, showing a continuous 13-hour e-VLBI run at 512 Mbps per telescope, the longest correlation job ever at JIVE

On **5 May 2008**, Hartebeesthoek Radio Astronomy Observatory in South Africa joined the e-EVN, through a rented connection from Johannesburg to London. An e-VLBI demonstration was done for a delegation of EU officials in Hartebeesthoek, within days of the connection being established. Although the expected bandwidth limit was 50 Mbps, the tests showed that 64 could be sustained, and even 128 Mbps for a short period. Other participating telescopes for the demonstration were Arecibo, Cambridge, Jodrell Bank, Medicina, Onsala and Torun. A fringe was detected on the Hartebeesthoek-Arecibo baseline, in spite of the limited mutual sky coverage. The remaining time was allocated between sources that could be observed by either Hartebeesthoek or Arecibo together with European telescopes.

On **9 May 2008**, the first e-VLBI test was carried out with the 6m Transportable Integrated Geodetic Observatory (TIGO) telescope in Chile along with Medicina and the Westerbork phased array telescopes in the X-band at 32 Mbps. Data were successfully transferred from TIGO, but there were fringes only on the Medicina-Westerbork baseline. After identifying the problem the schedule for TIGO observations was optimized and another test was carried out in the evening with TIGO and Arecibo. This resulted in first fringes to TIGO at 32 and 64 Mbps.

On **20 May 2008** the inclusion of telescopes with lower connectivity in high data rate experiments was successfully tested. This was done with the European telescopes and Arecibo, which, at that time, was limited to 150 Mbps. The schedule included data rate modes from 128 to 1024 Mbps.

The following day the first science experiment that included the Effelsberg telescope took place. The observations were carried out in the C-band at a data rate of 512 Mbps.

During a live e-VLBI demonstration at the TERENA Networking Conference 2008 in Bruges, Belgium on **22 May 2008**, telescopes in Africa, Europe, North and South America were for the first time linked to the central data correlator in the Netherlands, simulating a telescope almost 11,000 kilometers in diameter.

On **24-25 June 2008** three short projects were observed. One of the experiments targeted a radio source that is a possible counterpart to the variable gamma-ray source recently detected by AGILE in the Cygnus region. The e-EVN data show a compact component which may be partially resolved. This result was published in The Astronomer's Telegram #1597 <http://www.astronomerstelegram.org/?read=1597>.

On **7 July 2008**, formatted data was transferred from Westerbork to JIVE at a full 1024 Mbps. Because 1024 Mbps does not fit in a 1 Gbps Ethernet connection, the Linux "Ethernet bonding" driver was used to create a virtual network interface that consists of two 1 Gbps Ethernet cards. Traffic sent to this virtual interface was transmitted over both physical interfaces in a round-robin fashion so that even at 1024Mbps, each physical interface only transmits 512Mbps of the traffic.

The 34.4 km dark fiber between Westerbork and JIVE was recently upgraded to use multiple wavelengths (CWDM), with each wavelength able to carry 1 Gbps. Two of these wavelengths were used to bring both 1 Gbps Ethernet links to JIVE. There they were fed to the central switch/router, which was connected through a 10 Gbps Ethernet link to a Mark5A.

On **22 July 2008**, JIVE and the Multi-Element Radio Linked Interferometer Network (MERLIN, operated by Jodrell Bank Observatory) conducted an experiment to increase the number of MERLIN stations that can be used simultaneously for e-VLBI. By connecting the microwave links from the telescopes at Darnhall and Cambridge both to the VLBA rack in Jodrell Bank, and choosing a suitable LO frequency and track mapping scheme, data could be sent from both telescopes to the same Mark5A at Jb and from there to JIVE.

To achieve this, the "mirroring" functionality of the JIVE switch/router was used. This instructs the switch to copy any network packet it delivers to a particular port also to a "mirror" or monitoring port. An alternative implementation that uses IP multicasting to achieve the same duplication without having to reconfigure parts of our network was implemented at a later date.

On **28 August 2008,** dynamical switching between sources during an e-VLBI run was tested for the first time. The switch was made at Torun and Westerbork (in single dish mode) with Jodrell Bank remaining on the first source. Fringes were obtained to all three telescopes before, and again between Torun and Westerbork after the switch.

This first attempt at EVN dynamic scheduling showed that, in principle, on-the-fly schedule changes are feasible, with the caveat that the observing setup remains the same.

On **9 September 2008**, real-time fringes between Arecibo and several European EVN telescopes at a rate of 512Mb/s were demonstrated. This was made possible because of improvements in the network connectivity from Puerto Rico to the mainland USA via the PRISANET gigabit infrastructure jointly developed by the University of Puerto Rico, Centennial and the AO, and a dedicated network path all the way from Arecibo to JIVE.

On **30 September 2008**, a short science project was observed in the L-band at 512 Mbps. The results were used in a proposal for global (disk-based) follow-up VLBI observations of the target. The pipelined data were delivered just in time for the proposal deadline on the following October 1st.

On **10 October 2008**, an e-VLBI test was done using the Mark5A and Mark5B units at Westerbork. The Mark5A was attached to a single dish, and the remaining telescopes were fed to the Mark5B via the new digital Tied Array unit TADUmax. The telescopes were observing 4C39.25 at 5GHz. These were the first e-VLBI fringes with the Mark5B and the first e-VLBI fringes with TADUmax in Westerbork.

On **6 November 2008**, a Target of Opportunity (ToO) project was observed with the MarkII telescope at Jodrell Bank, Medicina, Onsala, Torun and Cambridge participating. During the first 1.5 hours fringe-finders were scheduled for data checking and clock searching, which, for the first time, was done in an automated fashion, without interrupting the correlation job. This considerably shortens the preparation time for e-VLBI observations.

The PI was able to begin analyzing data the following day, and the Astronomer's Telegram #1836 <http://www.astronomerstelegram.org/?read=1836>, including a preliminary e-VLBI map, was published two days later.

On **13 November 2008**, the full array was available, this time including Effelsberg, Westerbork, and Arecibo. Shanghai successfully participated in the initial fringe test part of the experiment. The data rate was 512 Mbps, except for Arecibo, which was limited to 128 Mbps. This was the first e-VLBI experiment in which the telescopes in Westerbork were remotely operated from Dwingeloo. More importantly, the new digital backend system (TADUmax) and a Mark5B were used in Westerbork for the observations.

In addition to the usual e-EVN array, a third MERLIN telescope participated in the experiment as well. Data from Knockin was streamed through the VLBA rack in IFs not in use by Cambridge, and ended up on tracks on the same Mark5A as used by Cambridge. The resulting data stream was then sent to JIVE as a Multicast data stream. Each receiving Mark5A at JIVE that is responsible for handling the data from one of the MERLIN telescopes can subscribe to this stream, which is only sent across once from Jodrell Bank to JIVE. This was the first time we used this new feature in a science observation, the second epoch observation of galactic radio-jet source SS433.

On **19 November 2008**, the third epoch observation of SS433 was observed in a similar fashion as the second epoch (13 November). However, an additional important milestone was achieved; three of the e-EVN telescopes, Effelsberg, Onsala and Westerbork observed and sent data at a full 1024 Mbps during the whole run, without dropping any data packets. This observation was also demonstrated live to attendees of the Effelsberg-Bonn Fiber Inauguration in Effelsberg, Germany.

In **December 2008** a number of tests took place including stations in Asia and Australia in preparation for the e-VLBI demonstration at the opening of the International Year of Astronomy 2009. The participating stations were ATCA, Mopra, Hobart, Kashima, Shanghai, Urumqi, all at 256 Mbps, except for Hobart, which was limited to 128 Mbps. These tests produced the first real-time fringes for Urumqi, Hobart, and Kashima. The data at Kashima were dynamically translated from K5 to Mark5B format. The demonstration itself will be discussed further on in this document.

On **22 January 2009** three science projects were observed at 18 cm. Shanghai participated along with the regular European e-EVN telescopes. As one of the projects required very high sensitivity, the 75m Lovell Telescope replaced the MarkII at Jodrell Bank. This was the first e-VLBI use of the LT.

On **10-11 February 2009**, two science projects were observed in the L-band at 512 Mbps. The first observation included Arecibo (at 256 Mbps) and most European EVN telescopes, including the Lovell, Cambridge and Knockin telescopes from MERLIN. Effelsberg did not participate, due to a

crack in the azimuth rail, and the Lovell Telescope also stopped after the first hour because a crack was discovered in the azimuth rail there, too. For the second project, Shanghai and the MarkII telescope joined in as well.

On **24-25 March 2009**, a "regular" and a triggered project were observed at 5 GHz with Cambridge, Effelsberg, Jodrell Bank (MkII), Knockin, Medicina, Onsala, Torun and Westerbork. This run featured a full 1024 Mbps data transfer from Effelsberg, Onsala, Torun and Westerbork.

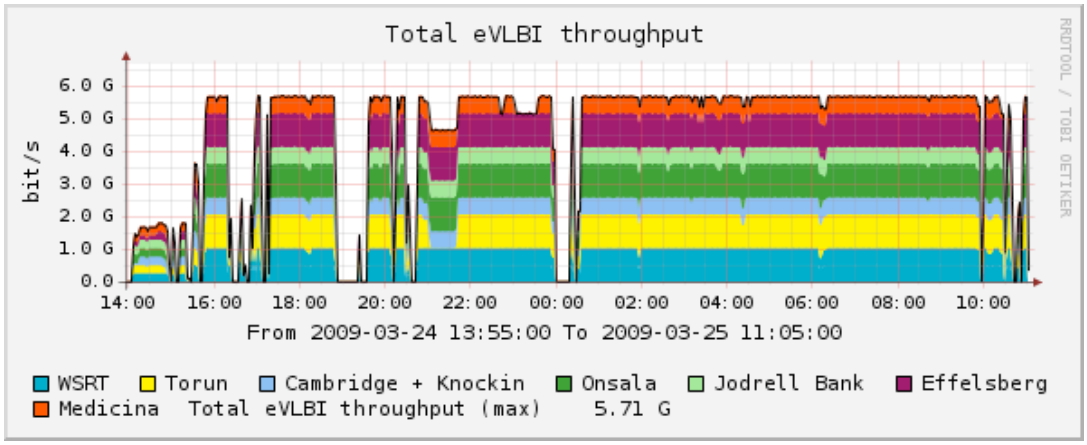


Figure: Data throughput at a full 1024 Mbps from 4 EVN stations

The e-EVN run on **21-22 April 2009** was very busy with two regular projects, a short request, and a ToO. This run was done at 1.6 GHz at 512 Mbps with Effelsberg, Medicina, Onsala, Torun, Westerbork, Shanghai, Cambridge, Jodrell Bank (Lovell), Darnhall, and Arecibo participating.. Arecibo was available only for the two regular projects because of initial connection problems. Eventually these problems were solved by re-routing to the regular network.

On **12-13 May 2009**, several EVN telescopes took part in a Target of Opportunity observation of Cyg X-2, including Torun, Cambridge, Knockin, Onsala, Jodrell Bank, Medicina, Shanghai, and Yebes, with Jodrell Bank participating at a full 1024 Mbps for the first time.

After the science run, several stations tested a Domino implementation for e-VLBI with a Mark5B. In this test, real-time fringes were detected for the first time from a Mark5B equipped station (Yebes) connected to a Mark5B at JIVE.

19-20 May 2009 saw the second epoch of a ToO project, and two regular observations. The array configuration and observing setup were similar to the 21 April run, except that Arecibo was not included and Darnhall was replaced by Knockin in MERLIN. One of the projects was badly affected by a 10-minutes BOCF jump (meaning a wrong time code was assigned to the data) in the correlator. The data were corrected afterwards. The loophole allowing this to happen was closed.

On **23 May** and **10 June** we carried out two epochs of our first ToO observations that requested a truly global e-VLBI array. Moreover, this was the first science project to be observed in the K band (22 GHz). The participating EVN telescopes were Cambridge, Jodrell Bank (MarkII), Effelsberg,

Medicina, Onsala, Metsähovi (epoch 2), Yebes (epoch 2) and Shanghai. Kashima joined from Japan, and Mopra and Hobart joined from Australia.

These two runs were challenging for a number of reasons. Three of the telescopes had not previously participated in regular e-VLBI runs with the EVN, but only in tests and demos, and the high frequency combined with the very long baselines complicated clock searching. Eventually the observations worked out very well, providing the longest e-VLBI baselines ever in units of observing wavelengths.

On **5 August** the first fringes to the new Miyun 50m radio telescope were detected with the JIVE software correlator (http://www.e-VLBI.org/tog/ftp_fringes/EY008A/index.html).

This was done in the course of a small VLBI experiment, proposed to test the EVN's compatibility with China's new Miyun 50m and Kunming 40m radio telescopes, and to study five bright GHz-peaked-spectrum radio sources. The other participating stations were Onsala, Medicina, Urumqi, and Sheshan.

Although this was not done in real-time, this test was an important step towards including the full Chinese VLBI network in e-observations. The EVN u-v coverage will be improved considerably through the addition of these telescopes.

Engineering developments

The SA1 team, thoroughly up to speed by the end of the second year of EXPReS, continued in the same composition. A large number of improvements and new developments took place, and any delays that occurred in the early phases of the project were more than compensated for during the no-cost half-year extension.

Software- Adaptive Scheduling

Software development efforts in the last 18 months of EXPReS focused on a number of distinct areas.

During the first two years of the project a fair amount of thought and effort had already gone into this development. Some of the major obstacles were the wide variety in operational setup at different stations, and the, understandable, reluctance of many station operators to allow outside interference with even part of the telescope control systems.

To alleviate these concerns, a schedule was devised in which no new software is installed at the stations at all, and no login sessions are initiated on the local Field Systems (FS); all communications from the correlator are done via ssh in single-command mode. By using the local FS and local procedures, all changes to the schedule are guaranteed to comply with local restrictions, and issues with local operation systems and FS versions are avoided. In addition, only changes to the order of previously approved sources or to the length of scans were allowed.

This system was finally tested with three EVN telescopes, Torun, Westerbork and Jodrell Bank, on August 28, 2008. After tracking one source with all three telescopes, the schedule was dynamically changed for Torun and Westerbork to another source, and after slewing fringes indeed did re-appear for these two telescopes.

In spite of this successful demonstration, and the safeguards, most telescope operators remain skeptical. However, it has been shown to be possible, and the developments in geodetic VLBI make it likely that in the future some form of remote control will also be introduced into astronomical VLBI.

Integration of Mark5B in EVN operations

As argued in previous reports, EVN operations would benefit from a general upgrade to Mark5B recording and playback units. The Mark5A system currently used by the EVN was designed as a drop-in replacement for tape recorders, preserving all quirks and peculiarities of handling tape-based data formats. The Mark5B however marks a clean break with the relics of tape technology and is fully VSI-compliant.

Upgrading to Mark5B would among other advantages allow JIVE to phase out their ageing (and failing) pieces of custom-built hardware called the Station Units (SUs). The function of these SUs is to re-create the originally observed data stream from the recording, apply a geometrical delay model and pass the synchronized data streams on to the correlator. Operations like multiplexing/de-multiplexing, checking of validities and stripping of time-codes are all done inside the SU. The Mark5B will completely take over this SU functionality, accepting VSI data streams and presenting the data streams in a simple tape-format to the correlator.

Part of the work was outsourced to Haystack observatory, the original designers of the Mark5 system. Although by the end of year 2 a sizeable amount of code had been produced, in the end a large programming effort was still required locally at JIVE to make a working, e-VLBI capable Mark5B playback system and integrate it fully into the EVN correlator system. This has, unfortunately, led to a quite serious divergence of different Mark5B code bases.

The e-VLBI sending part of the Mark5B system was fully integrated into the locally developed jive5A Mark5 control code.

The introduction of Mark5B into EVN operations however has been disappointingly slow. Only very few stations use Mark5B units (Westerbork, Yebes, Effelsberg only occasionally, the QUASAR network), and other stations have been reluctant to upgrade, as it would involve costly and labor-intensive modifications to their equipment. Most stations now await the delivery of digital base band converters (dBBCs), which are finally becoming available. As the dBBCs will allow higher bandwidths to be exploited, some stations are now considering moving directly to the, not yet available, Mark5C or equivalent 4Gbps recording systems. This may cause yet further delays and force JIVE to keep operating the SU units even longer.

Streamlining operational data rate adjustments

At the end of year 2 packet dropping had been implemented and successfully demonstrated, enabling us to basically fill any available link to its limit. Packets, without headers, are dropped at the sending side, and the gaps in the data stream are filled with dummy data at the receiving side. This allows the correlator to keep synch, while the dummy data are flagged as invalid. Operationally, this method has a serious drawback, apart from the obvious loss of sensitivity across the observed bandwidth. As we have no way of synchronizing the dropping of packets at different stations to sufficient accuracy, applying this scheme at many stations simultaneously rapidly increases the loss of sensitivity. Still, for individual stations with poor connectivity this method has proved very useful.

Channel dropping, a much cleaner way of fitting the data rate from the stations to the available bandwidth, was further developed and demonstrated, first with the Mark5A, and through a considerable programming effort, also for the Mark5B. Deployment of this method however has been slow. One problem is that it is very CPU intensive. This is no problem when dual processor or multiple core machines are used, but not all stations have the right equipment, or even the right operating systems capable of handling multiple cores. This problem however will disappear when the

newest Linux kernels become available (which in turn depends on the availability of compatible StreamStor libraries).

With the capability to schedule different observing modes at different stations simultaneously (limited by hardware to power-of-two "octaves"), and with more and more stations connected at more than 1 Gbps, allowing full 1024 Mbps data transfers, channel dropping has lost some of its importance. However, we expect some stations to benefit from it in the next sessions, most notably the new Yebes radio telescope.

Further improving the robustness and flexibility of the correlation process

Over the years, many e-VLBI-specific features have been added to the EVN correlator system at JIVE. In several cases, as an additional bonus, this led to marked improvements of the behavior of the system in normal disk-based operations. On the other hand, the real-time nature of e-VLBI forced us to streamline many facets of the correlation process.

Efforts continued in the last 18 months to make, and keep, e-VLBI as reliable and "user-friendly" as disk-based VLBI operations. This means that new features, while well understood by the engineers, had to be equipped with intuitive user interfaces as quickly as possible, to ensure that the correlator operators would be able to use these features when the engineers are sleeping at night. Judging from the remarkably unremarkable e-VLBI runs of the past months, this has been quite successful.

On-the-fly fringe fitting was introduced, and has since been used extensively in both electronic and disk-based VLBI. Lightpaths tend to go down fairly regularly, so a system was set up which ensures automatic re-routing via the switched network in case of failures (although sometimes this means the data rate has to be decreased). Real-time download of station information was implemented, giving instant access to the log files created at the stations. At this moment, the only information displayed is the system temperature and on source/off source status, but any other log item can be added easily. Mixed-mode operations were partly enabled, which means that simultaneous recording/electronic transmission at the stations is now possible. Simultaneous playback/recording at the correlator is only possible with the Mark5B system, and as explained earlier in this report, not many of these are in use yet.

Increasing the data rate beyond 1 Gbps

While it is possible to optimize the use of 1 Gbps links by dropping packets and channels and by mixing operational modes, ideally one would like to send the full 1024 Mbps. What is more, the EVN is already looking into the possibility to increase the data rate of several European telescopes to 4 Gbps. In order to bring e-VLBI to the same level of sensitivity as disk-based VLBI, and to investigate future upgrades to 4 and possibly 10 Gbps, the connections to a number of stations were upgraded, in a number of ways.

The first and most obvious candidate for an upgrade was the Westerbork radio telescope. Located at a distance of only about 35 km, it is connected via dark fiber to Dwingeloo. Using surplus DWDM equipment from LOFAR, 3 colors were lit, each carrying 1 Gbps. Two of these are used to transfer 512 Mbps each, through a round-robin scheme, and connected to the central router at JIVE. From there, the reconstructed 1024 Mbps data stream is sent via 10 G equipment to a Mark5.

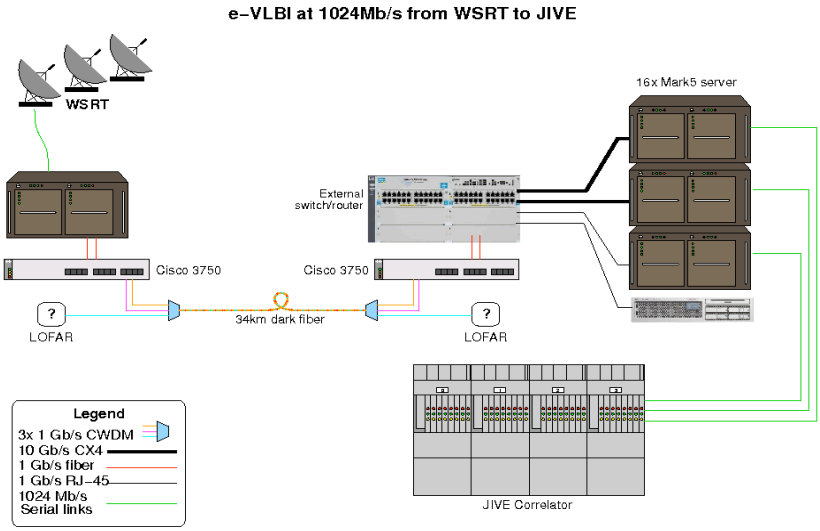


Figure: upgraded connection between the WSRT and the correlator at JIVE

The expansion of LOFAR into E-LOFAR (which stands for European LOFAR), meant that suitable locations for new LOFAR stations had to be found; in two cases (Effelsberg and Onsala) the decision was made to place them near existing radio telescopes, in order to take advantage of the local infrastructure and connectivity. With far higher data rates than current e-VLBI (4 Gbps), data transport to the Blue Gene correlator in Groningen, the Netherlands, posed quite a challenge.

Two different approaches were taken. In the case of Effelsberg, the new fiber connection from the radio telescope to the institute in Bonn, funded by the Max Planck Institute to support the EXPReS project, could be shared, with e-VLBI and E-LOFAR traffic using separate VLANs. From Bonn a 10 G border-crossing fiber via Juelich to SURFnet in Amsterdam was provided, where the VLANs split and continue to Dwingeloo and Groningen. As the 10 G connection has ample capacity for both applications, it now became possible to send e-VLBI data at a full 1024 Mbps

In the case of Onsala, NORDUNET had to accommodate E-LOFAR traffic to Groningen, e-VLBI traffic to Dwingeloo and e-VLBI traffic at 4 Gbps to Jodrell Bank, as part of the FABRIC JRA of EXPReS, in which Onsala was to be connected to the new e-Merlin correlator. To do so, they set up a so-called L2 TSS cloud, which basically is a VLAN switch. With 4 Gbps at our disposal, 1024 Mbps has been the operational data rate from Onsala since then.

Following this, the Torun-Poznan connection was upgraded by the Polish NREN to 10 G. After replacing all local equipment with 10 G gear, 1024 Mbps data could be sent via the routed GÉANT2 network to JIVE.

Finally, the same method used for the connection to Westerbork was used for the connection to Jodrell Bank. 1024 Mbps is divided over the two available 1 G links and recombined at the correlator. In order to use 1024 Mbps from one Jodrell Bank station in combination with the so-called Merlincast, the inclusion of multiple Merlin stations through multicast, the round-robin scheme was altered to allow an uneven distribution of packets. This was then dubbed “elliptical robin”.

Metsahovi radio telescope was connected at 10 G very early on in the project. However, because of its somewhat limited frequency overlap with the majority of the EVN telescopes, it has only ever been used in e-VLBI demos, and never at a full 1024 Mbps.

Hardware Developments

All Mark5s at the correlator were equipped with 10 G NICs, and new 10 G modules were installed in the central router. Several Mark5A units were modified to Mark5B, and back, as global observations necessitated the use of 16 Mark5A units. One spare Mark5B was purchased to function as development platform. For an extended period of time this unit was used at Westerbork, to help with the debugging of and transition to the new TADUMax backend.

A new machine, identical to and exchangeable with the two correlator control computers, was purchased as a new data acquisition platform. All data reduction was transferred to the PCInt cluster.

Connectivity improvements: China, Australia and Japan

During 2007 a number of international demonstrations showed convincingly that long haul, high-rate data transport was feasible. After these demos, two of the three 1 Gbps lightpaths connecting the Australian VLBI network to JIVE were removed by AARNET, but one stayed in place, and has been in use on a regular basis.

The connection to the Sheshan telescope near Shanghai was operational throughout, mostly through a 622 Mbps GLIF lightpath via Hong Kong and Canada to the Netherlands and JIVE. An alternative route via Beijing and the TEIN2 network remained possible and was used occasionally. However, as the data rate via Siberia is limited to 256 Mbps, the lightpath remains the preferred option.

Several demonstrations took place during the last 1.5 years of EXPReS. The most ambitious and in many ways the most successful of these was the 33 hours continuous monitoring of a number of sources using a global array of telescopes, at the opening ceremony of the International Year of Astronomy in Paris, in January 2009. This demo will be described in more detail in a next chapter. Several telescopes that had never before been involved in e-VLBI with the EVN joined this demo. For this purpose the Urumqi telescope obtained a one-month 622 Mbps connection to Beijing, and in fact participated successfully. Unfortunately the cost of this connection was too high to sustain, and there have been no further e-VLBI sessions with Urumqi.

Kashima radio telescope, in Japan, also joined the demo. Here the problem was different, namely that the data had to be re-formatted on the fly to the Mark5B format. In close collaboration with the Australian colleagues, who had implemented a similar conversion the previous year, a K5-Mark5B conversion utility was written, debugged and deployed. The data from Kashima were sent through the routed network to JIVE, as no lightpaths were available.

Connectivity Improvements: Puerto Rico, Chile and South Africa

The connection of the Arecibo radio telescope, the largest in the world, to mainland USA was finally upgraded. A VLAN was provided by the Caribbean NREN and Internet2, and thanks to their efforts sustained 512 Mbps data transfers became possible. Although this data rate is limited to pre-arranged short periods, 128 Mbps is now available all the time, and Arecibo has participated in many science and testing sessions since.

Connectivity to TIGO remained stable at 64 Mbps. Research was done at TIGO to investigate the possibility of using many parallel TCP streams, via different paths, to overcome bandwidth restrictions. However this method has not been tested in e-VLBI operations.

The network connection from Johannesburg to Hartebeesthoek radio telescope in South Africa was upgraded to 1 Gbps in the spring of 2009. In order to participate in the e-VLBI demonstration at the TERENA conference in Bruges, Belgium, a one-month 50 Mbps connection was leased to London. Within three days of this connection becoming available, a demonstration with fringes between Hartebeesthoek and several EVN telescopes was staged before a visiting delegation of high-ranking EU-officials. After participation in the TERENA demo however the link was discontinued, due to the extremely high cost. On top of this, a serious mechanical failure later that year made it unclear if the telescope was to remain operational at all. At the time of this writing however reparations of the telescope are underway, and a 10 G connection to Europe is expected to be in place soon.

Connectivity Improvements: Europe, Russia

The physical connections to European telescopes stayed largely as they were, with improvements. Towards the end of the second year of EXPReS 512-Mbps e-VLBI runs with all European telescopes had become commonplace, and, using packet dropping, successful runs at (near) 1 Gbps had taken place. Eighteen months later, many telescopes are regularly participating at a full 1024 Mbps. Various Merlin telescopes are included in the array at various times, greatly enhancing the sensitivity to large structures.

The newly built Yebes Radio Telescope was taken into operation in 2008, and saw its first VLBI light via electronic transfer, which is definitely a first. It now participates on a regular basis in e-VLBI sessions.

The situation for the Irbene Radio Telescope near Ventspils, Latvia, has unfortunately not improved. Connectivity is available, but problems with the equipment at the station have prevented it so far from producing usable VLBI data. Hopefully this situation will improve soon, when modifications to the dBBC at Ventspils have been implemented.

Finally, the QUASAR network of Russian radio telescopes joined the EVN. Some preliminary data transfer tests from Badary, a telescope located in East Siberia, showed it would be possible to sustain 32 Mbps, sufficient for spectral line observations. A first fringe test is currently being planned.

Demonstrations, and more demonstrations

Many demonstrations took place during this period. As in previous years, they were disruptive to normal operations, labour-intensive, and caused a great deal of frustration among the participants. At the end of the day however, they were extremely useful as focal points, stimulating a lot of developments and ultimately reaching large audiences.

The first demonstration was an ad-hoc affair to mark the visit of a delegation of EU-officials to Hartebeesthoek radio observatory. As mentioned before, this was set up within 3 days of the physical connection to Hartebeesthoek becoming available, clearly demonstrating the progress e-VLBI has made.

This was followed by the TERENA demonstration in Bruges, Belgium. At this demo, 4-continent e-VLBI actually produced 4-continent fringes. The results were shown live by the JIVE director, Huib van Langevelde, during his keynote address to the plenary session.

Figure: JIVE staff member watching Huib van Langevelde delivering his keynote address at the TERENA conference in Bruges

This was followed by a more modest demo at the GLIF meeting in Seattle in autumn 2008, during which live results were shown in real-time to the audience.

The next demonstration however was far more ambitious, in fact the most ambitious so far. As the International Year of Astronomy was to begin in January 2009, the EVN was looking for ways to profile itself. This was done by staging a 33-hours continuous tracking of 3 sources, using a global array or radio telescopes, many of which had never participated in e-VLBI sessions with the EVN before (originally planned as the 24 hour tracking of one source). The venue would be the opening ceremony of the International Year of Astronomy, at the UNESCO building in Paris, January 2009.

Figure: JIVE staff and EVN officials explaining real-time e-VLBI at the opening of the IYA in Paris

Many problems had to be overcome to make this possible. First of all, no less than 4 of the 18 participating telescopes were completely new to the e-EVN (Urumqi, Kashima, Westford and Hobart). Four different data acquisition systems had to be taken into account, data would arrive at JIVE from 5 continents, and 2 frequencies had to be used. To make matters worse, the Effelsberg track developed a crack just before the observations, severely limiting its range, the power supply in the Torun Mark5 unit broke, forcing staff members to rush into town to find a replacement, memory modules had to be swapped in the Mark5 unit at TIGO, and last minute adjustments had to made to the bit mapping scheme at Kashima. Heroic efforts were made, and in fact, nearly all stations started transmitting data on the dot.

A large number of special tools and displays were created for this event, bundled in a publicly accessible webpage. Among them were near real-time imaging of the sources, a page with webcams of the participating telescopes, a real-time build-up of the UV plane coverage, and an extremely useful VLBI simulator, showing the effects of different baselines on different types of sources. With an audience consisting of mainly astronomers, the JIVE-EVN team had an extremely busy time answering many very well informed questions.

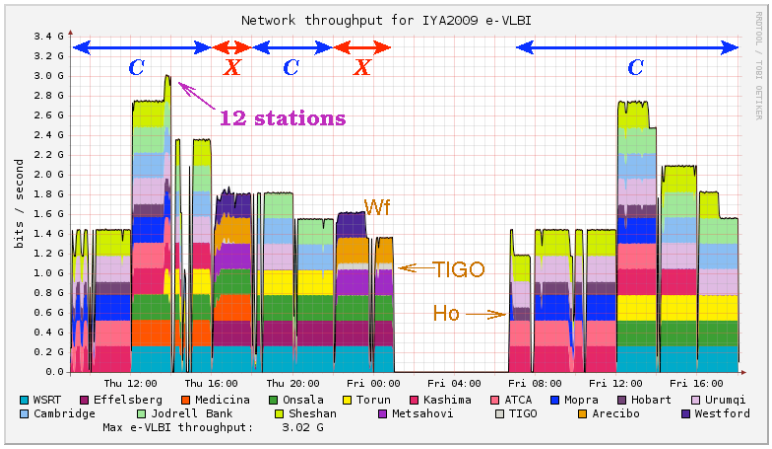


Figure: resulting throughput plot of the "33 hours of e-VLBI"

A somewhat toned-down version of this demo was held during the other high-profile astronomical event of the IYA, the "100 hours of astronomy", during which live interviews with observatories around the world were broadcast on the Internet. The results were shown live, among others, at the open day at the NEMO science museum in Amsterdam and at the open days at the Bordeaux and Arecibo observatories.

University of Manchester

UNIMAN's role in this project is the addition of multiple telescopes in the UK to European e-VLBI operations. Since e-MERLIN, now under construction, uses digital data links over optical fibre, the project concentrated on interfacing the digital output (via an FPGA on the e-MERLIN station board) to 10 Gbps Ethernet connection on CX4 which can be sent on the international network via a switch. The complementary action, studied in JRA1 receives a high data rate signal from Onsala to be correlated with the rest of e-MERLIN telescopes is achieved by the same equipment.

eMERLIN Interfaces

Considerable progress has been made during the year, with the development of the interface cards (University of Berkeley's iBOB boards) driving UDP protocols.

Figure 1 shows the overall configuration, with the e-MERLIN-in connection from Onsala also shown. The interfaces work correctly and indeed have been developed as network testing devices (iNetTest), and have been used by Dante on the GEANT network.

Note that the correlator is being manufactured by NRC, Penticton, Canada. eMERLIN boards have the same design as those being built for the EVLA, but eMERLIN uses approximately 1/16th of the total number of boards required for the EVLA. A station board was delivered in January 2009, and a second station board and a baseline board were delivered in March 2009. First fringes were obtained in Sprint 2009.

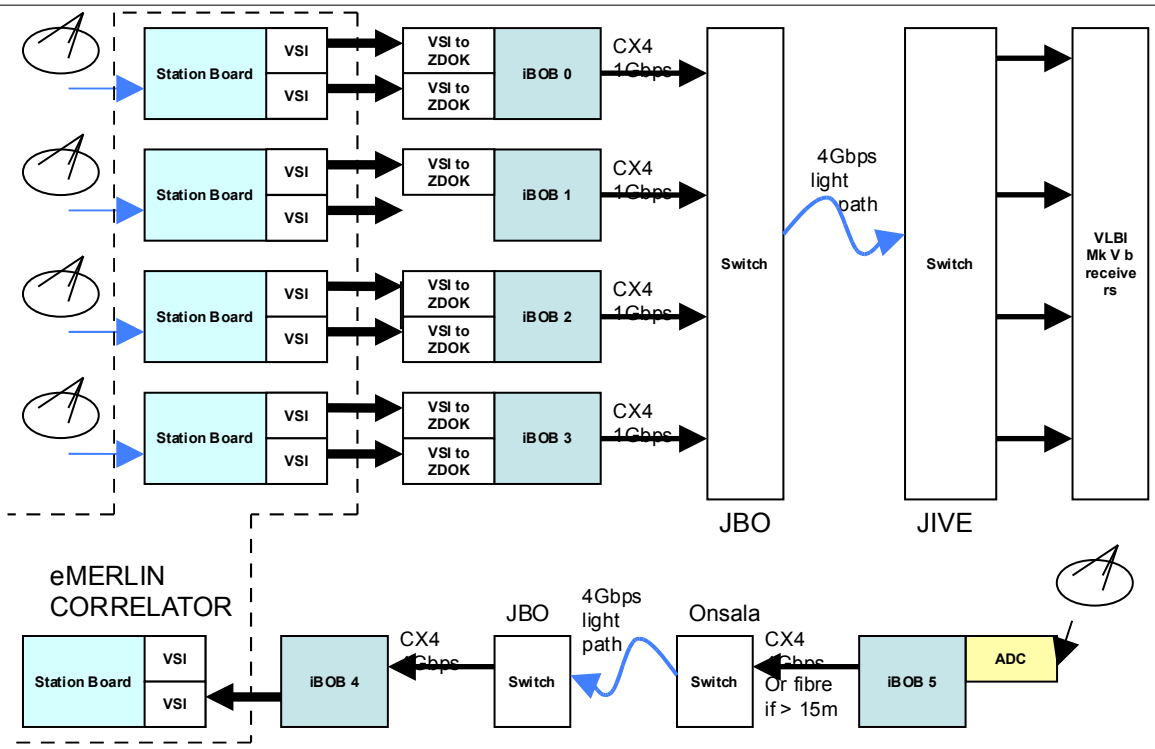


Figure: Block diagram of connection in and out of the e-MERLIN correlator for both SA1 and JRA1. Data rates are limited by the capabilities of the links, at the moment this is 1 Gbps for 3 e-MERLIN telescopes out, and 4.2 Gbps in.

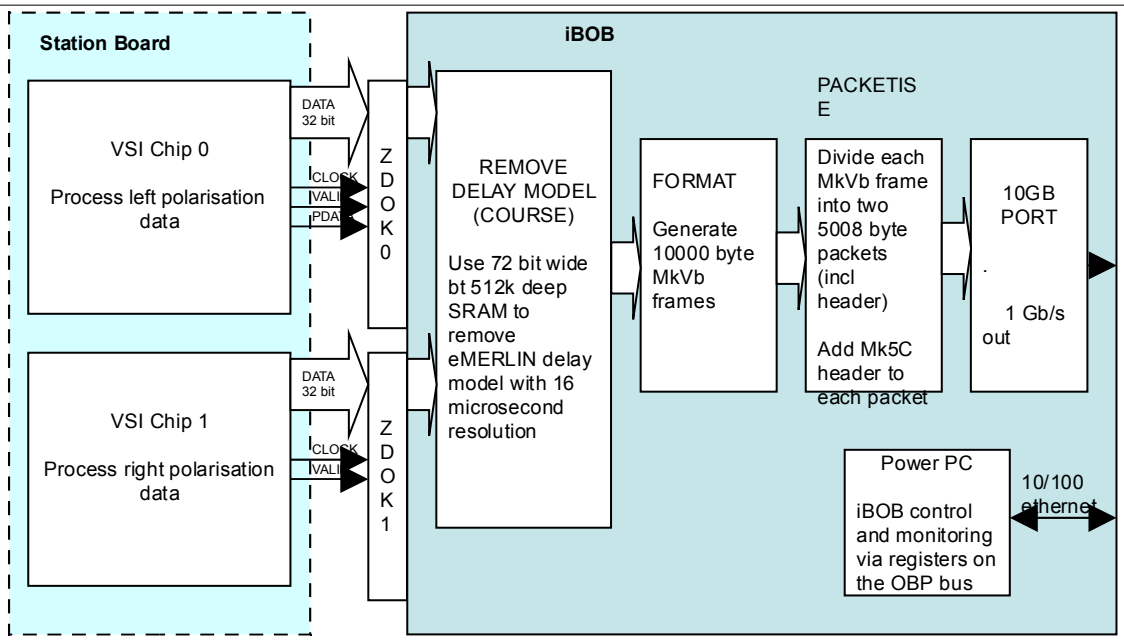


Figure: Overall view of functionality for e-MERLIN out. The required FPGA code is split between the 'VSI' chip a Vertex 4 FPGA on the station board, and the Vertex 2 chip on the iBOB.

As a result of delays in delivery, much of the work described here was performed using simulations, however porting onto the real devices proved to be fairly smooth and trouble free. Most of the effort during the year was therefore concentrated on the network interfaces in the IBOBs (see under JRA 1.2).

Figure 2 shows how the functionality is divided between the VSI interface FPGA on the station board, and that on the iBOB. The bulk of the code in the iBOB is concerned with packetisation and transmit control, whereas that on the VSI chip is concerned with channelisation. into bands which match VLBI needs. Code for these tasks has been implemented and the specific tasks for the VSI chip on the station board to perform are as follows:

- Select one or more 128MHz, 4 bit resolution or 64MHz , 8bit bands from the filter bank as input
- Remove the fine part of the eMERLIN delay (62.5ps – 16ns)
- Remove the N x 10kHz offset (the WIDAR Correlator relies on frequency offsets between telescopes
- Extract sixteen bands of up to 8MHz and possibly support eight bands of 16MHz (1Gbps = 2 pol x 2 bits x 2 x 8 MHz x 16 bands)

These tasks are outlined in the figure below.

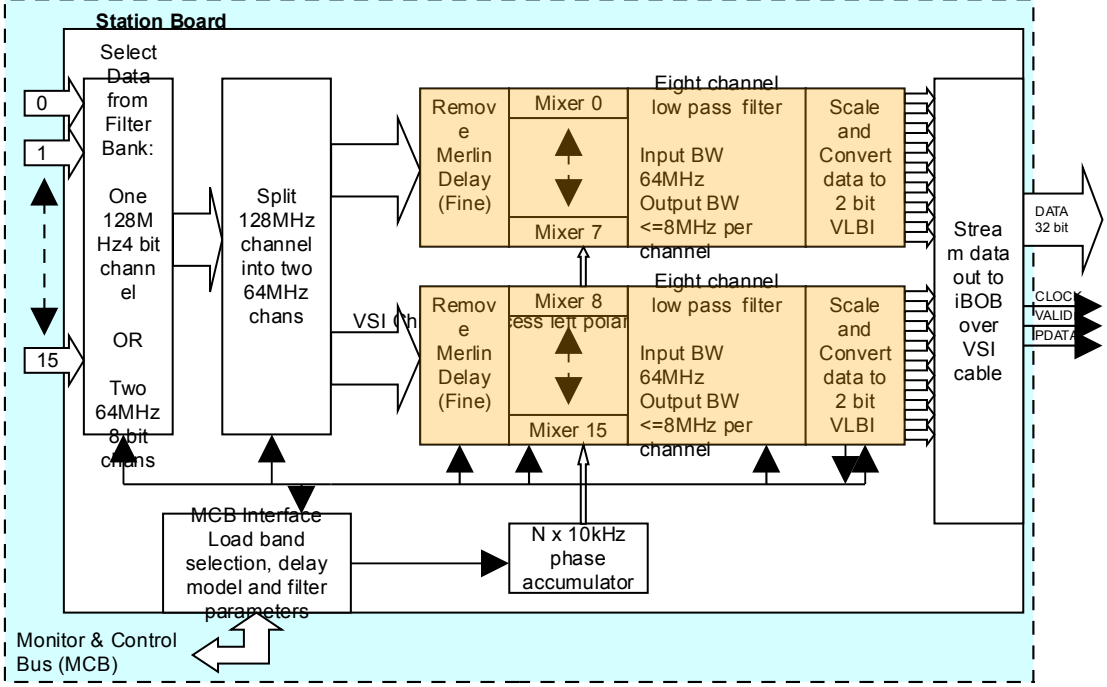


Figure: Functionality of the VSI chip Low pass filtering is by FIR digital filters

Multiple telescopes with narrow bands

The inclusion of MERLIN telescopes into EVN gives improved uv coverage and sensitivity, and is often requested by observers. In view of the astronomical need it was decided to develop this using the 2 x 1 Gbps light paths to JIVE currently available. An alternative multi-telescope connection to JIVE uses the existing analogue links and VLBI equipment. One wideband (<=1Gbps) Station (one of the local telescopes ay Jodrell Bank, is used along with up to 3 remote telescopes operating at the lower data rate of 128 Mpbs. The signals from the remote telescopes make use of the VLBA data acquisition rack, producing a system which is suitable for Mk5 recording or network transmission. The EVN Correlator duplicates data streams so that full correlation can be obtained. Details of how multitasking techniques enable the signals to be processed are given in D150 Protocols Performance Report by S. Kershaw et al. Results from experiments using this system are described elsewhere in this annual report and we have partially met D85, multiple telescope e-MERLIN tests.

1.5.1.2 SA1 Participating Institutions[15]

The majority of NA4 activity takes place at JIVE with the employment of the EXPReS Public Outreach Officer, and production of publicity materials.

[15] Participation is based on those institutions who have received funding for the activity. The Participating Institution Table assumes the following abbreviations:
P # - Participant Number

#	Short Name	P3 Claim (EUR)[16]
1	JIVE	0
18	UniMan	27,277.88
	total	

1.5.1.3 SA1 Deliverables and Milestones Tables

D#	AD#	Deliverable Description	Lead	Delivery Month		Status[17]
				Planned	Actual	
12	1.03	Fast/adaptive scheduling tools: Dynamic scheduling of the e-EVN	JIVE	36	36	4
27	1.04	eMERLIN VSI interfaces design	JBO	22	41	4
36	1.07	Monitored information handling modules	JIVE	42	42	4
45	1.09	Tests using local Jodrell Bank home e-MERLIN telescope	JBO	22	41	4
52	1.14	Test using remote e-MERLIN telescope	JBO	24	41	4
53	1.16	VSI support software (Gzipped tarfile of modified SU control code, Controlling the Mark5B playback unit from JCCS, Domino: Mark5B control software	JIVE	28	38	4
85	1.19	Multiple e-MERLIN telescope tests	JBO	24	41	4
95	1.2	Improved network applications (tarball of locally developed Mark5 control code, jive5a history and download page)	o/s	27	30	4
126	1.23	Use of WSRT synthesis data for e-VLBI calibration	JIVE	17	22	4
127	1.24	Mark5A code modifications (OS and application upgrade, from Debian Sarge to Debian Etch with SDK8.1, jive5a history and download page)	o/s	27	30	4
128	1.25	Mark5B code modifications (tarball of locally developed Mark5 control code, Domino: Mark5B control software)	o/s	27	31	4
151	1.28	On-the-fly fringe fitting (On-the-fly clock searching)	JIVE	28	28	4
152	1.29	Real-time download and extraction of station information: Monitoring the EVN via Field System logfiles	JIVE	30	32	4

[16] Period 3 figures are based the most accurate figures available at the time of writing. Many partners were in the process of their audits and expect changes to these figures. Official figures will be provided as soon as they are available.

[17] The status of the deliverable is tracked on a 0 to 4 scale with 0 indicating no work started and 4 indicating that the deliverable has been accepted by the project office.

156	1.3	Automatic diagonal weight detection, Automated correlator diagnostics	JIVE	33	41	4
162	1.32	Enhancements & additions to real-time pipeline: Enhancements to the easyJIVE web-driven post-processor tool	JIVE	42	42	4
163	1.33	Enhancements & additions to existing monitoring tools: Extensions to the Data Status Monitor tool	JIVE	42	41	4
166	1.34	Mixed-mode operations: Tarball of locally developed Mark5 control code	JIVE	38	35	4
167	1.35	1024 Mbps e-VLBI and beyond (e-VLBI beyond the 1Gb/s speedbump, Throughput plot of e-VLBI run on October 19 2008, with the Effelsberg, Jodrell Bank and Westerbork radio telescopes transmitting data at a full 1024 Mbps, Metsahovi four-Gbps data recorder for VLBI and e-VLBI, iBob data acquisition and network streaming)	JIVE	40	36	4

1.5.1.4 SA1 Human Resource Overview

Staff funded by EXPReS:

Name	Position Title	Position Location (Short Name)	Position Description	Start Month
Zsolt Paragi	e-VLBI support scientist	JIVE	Scientific support, scheduling, testing of new capabilities	1
Bob Eldering	Scientific software engineer	JIVE	Correlator control & monitoring software	3
Des Small	Scientific software engineer	JIVE	Data reduction and scheduling software	4
Paul Boven	Network/Linux Specialist	JIVE	Hardware upgrades and network design, internet protocol investigation	10
Jonathan Hargreaves	Digital engineer	UniMan	Interface e-MERLIN – e-EVN	10

Contributions not funded by EXPReS:

Name	Position Location (Short Name)	Position Title
Arpad Szomoru	JIVE	Planning, representation, outreach
Friso Olnon	JIVE	Correlator control software
Mark Kettenis	JIVE	Real-time correlator code, transport protocol modifications
Harro Verkouter	JIVE	Mark5A and B control code, transport protocols

Michael Lindquist	Onsala	Reseach Engineer
Roger Hammargren	Onsala	Senior Technician/Chief telescope Operator
Simon Garrington	UniMan	Director, signing authority
Ralph Spencer	UniMan	Project Manager
Richard Hughes-Jones	UniMan	Network scientist
Paul Burgess	UniMan	VLBI engineer
Tony Rushton	UniMan	PhD student
Steve Kershaw	UniMan	PhD student
Althea Wilkinson	UniMan	administration assistant

1.5.1.5 Meetings and Workshops

Date (month)	Event Description / Location
2 Apr 2008	Radio Astronomy in the era of high-speed networks; STOA/TERENA Workshop, Brussels, Belgium
9-11 Apr 2008	e-VLBI Networking Challenges; NORDUnet 2008, Espoo, Finland
14-16 May 2008	Real-Time VLBI observations of compact objects; VSOP-2 Technical Meeting, Bonn, Germany
19-22 May 2008	e-EVN: a real-time telescope larger than Europe; Terena Networking Conference, Bruges, Belgium
30 May 2008	SA1: Production e-VLBI service; EXPReS Annual Review, Brussels, Belgium
30 May 2008	URSI Forum 2008; Brussels, Belgium
4 Jun 2008	WSRT for EVN amplitude and polarization calibration, and for triggering transients; WSRT users meeting, Amersfoort, The Netherlands
16-17 Jun 2008	e-VLBI beyond the 1Gb/s speedbump; 7th International e-VLBI Workshop, Shanghai, China
16-17 Jun 2008	4 Gigabit Onsala - Jodrell lightpath for e-VLBI - The iNet test unit - Development of real time e-VLBI at Jodrell Bank Observatory; 7th International e-VLBI Workshop, Shanghai, China
16-17 Jun 2008	e-EVN science projects (2006-2008); 7th International e-VLBI Workshop, Shanghai, China
16-17 Jun 2008	EXPReS and the e-EVN; 7th International e-VLBI Workshop, Shanghai, China
16-17 Jun 2008	The road to 980Mbps e-VLBI; 7th International e-VLBI Workshop, , Shanghai, China
16-17 Jun 2008	iBOB data acquisition and network streaming; 7th International e-VLBI Workshop, Shanghai, China
7-16 Aug 2008	e-VLBI: a real-time telescope of intercontinental dimensions; 2008 URSI General Assembly, Chicago, USA
4 Sep 2008	ADAPTNET - The Future is wide; EXPReS meeting, Jodrell Bank, UK
4 Sep 2008	4 Gigabit Onsala-Jodrell Lightpath for e-VLBI - The iNET test unit; EXPReS meeting, Jodrell Bank, UK
4 Sep 2008	e-MERLIN Data Import and Export; EXPReS meeting, Jodrell Bank, UK
4 Sep 2008	Recent e-EVN Developments; EXPReS meeting, Jodrell Bank, UK
Sep 2008	High Performance Networks in Radio Astronomy; ECOC2008, Brussels, Belgium
22 Sep 2008	EVN/JIVE technical developments; TOG meeting, Bologna, Italy

22 Sep 2008	Dynamic scheduling of the e-EVN: a progress report; TOG meeting, Bologna, Italy
23-26 Sep 2008	EXPReS and the e-EVN; 9th International European VLBI Symposium, Bologna, Italy
23-26 Sep 2008	Type Ib/c supernovae with the EVN; 9th International European VLBI Symposium, Bologna, Italy
23-26 Sep 2008	Towards the Next Generation of e-VLBI; 9th International European VLBI Symposium, Bologna, Italy
25 Sep 2008	Experience with e-VLBI (from a user's perspective); EVN Users meeting, Bologna, Italy
1-2 Oct 2008	e-VLBI: real-time radio astronomy; 8th Annual GLIF Workshop, Seattle, USA
29-30 Oct 2008	Visit to IBM Zuerich, Switzerland
Nov 2008	Optical Fibres and Radio Astronomy; Jodrell Bank Symposium, Jodrell bank, UK
3 Nov 2008	EXPReS and the e-EVN; EVN Science Day, Arecibo, Puerto Rico
20 Nov 2008	Inaugruation of the High-Speed Fibre Optic Link for e-VLBI; Effelsberg, Germany
Dec 2008	Challenges for the Data Network; Electronics Knowledge Transfer Network workshop on SKA, Cambridge, UK
1-2 Dec 2008	International Lightpath Experiences; TERENA E2E Workshop, Amsterdam, The Netherlands
16-20 Mar 2009	IVS Workshop on Future Radio Frequencies and Feeds, Wettzell, Germany
21 Mar 2009	IVS DBE and Correlator meeting, Wettzell, Germany
17 Apr 2009	EVN/JIVE Technical Developments; TOG meeting, Torun, Poland
20 Apr 2009	The e-EVN: a realtime VLBI instrument; European Week of Astronomy and Space Science (JENAM), Hatfield, United Kingdom
20 Apr 2009	e-EVN and global VLBI observations of SN 2007gr; European Week of Astronomy and Space Science (JENAM), Hatfield, United Kingdom
26 May 2009	e-EVN Update; EVN Board Meeting, Gothenburg, Sweden
8-11 Jun 2009	Worldwide Networking for e-VLBI; TNC2009, Malaga, Spain
22-26 Jun 2009	A suspected Dark Lens revealed with the e-EVN; The 8th International e-VLBI Workshop, Madrid, Spain
22-26 Jun 2009	Progress and Status of e-MERLIN; 8th International e-VLBI Workshop, Madrid, Spain
22-26 Jun 2009	iNetTest a 10 Gigabit Ethernet Test Unit; 8th International e-VLBI Workshop, Madrid, Spain
22-26 Jun 2009	Commissioning and Using the 4 Gigabit Lightpath from Onsala to Jodrell Bank; 8th International e-VLBI Workshop, Madrid, Spain
22-26 Jun 2009	e-EVN Progress, 3 years of EXPReS; 8th International e-VLBI Workshop, Madrid, Spain
22-26 Jun 2009	e-VLBI Networking Tricks; 8th International e-VLBI Workshop, Madrid, Spain
2 Jul 2009	Very Long Baseline Interferometry (VLBI) in the 'golden age' of radio astronomy; 1st School on Multiwavelength Astronomy, Paris, France

1.5.2 SA2- Network Provisioning

1.5.2.1 SA2 Activity and Status

The Service Activity 2 Network Provisioning is focused on physically connecting partners to the shared network infrastructure. The network connectivity is the "e" in e-VLBI and is a foundation of the project. As mentioned in previous reports, Commission support for connectivity was instrumental in generating interest, unlocking support and obtaining associated funding to help connect the sites. Most sites were connected in the first two periods of the project and continue to participate actively in e-VLBI.

Over the course of the project, telescopes have evolved from not connected to fully connected and operational sites. With the close of the project, we are able to show the success of the activity and the progress made in e-VLBI for the community at large. The table below shows the production capability of sites in the early stages of the project and the level to which sites now regularly participate in production e-VLBI.

Table: Comparison of the production network speeds for EXPReS participants

Station	Production Capability		Highest Tested	Network Capability
	May-06	Aug-09		
Arecibo		512 Mbps	512 Mbps	512 Mbps
CSIRO		512 Mbps	512 Mbps	1 Gbps
Effelsberg		1024 Mbps	1024 Mbps	10 Gbps
Haartebeesthoek			64 Mbps	
Jodrell Bank	256 Mbps	1024 Mbps	1024 Mbps	2 x 1 Gbps
Medicina	256 Mbps	512 Mbps	512 Mbps	1 Gbps
Metsahovi		1024 Mbps	1024 Mbps	10 Gbps
Onsala	256 Mbps	1024 Mbps	1024 Mbps	1.5 Gbps
Shanghai		512 Mbps	512 Mbps	622 Mbps
TIGO		95 Mbps	95 Mbps	95 Mbps
Torun	256 Mbps	1024 Mbps	1024 Mbps	1 Gbps lightpath + 10 Gbps routed
Ventspils				1 Gbps
WSRT	256 Mbps	1024 Mbps	1024 Mbps	2 x 1 Gbps
Yebes		512 Mbps	512 Mbps	1 Gbps

The diagram below highlights how the 19 partners inside of EXPReS- astronomy institutes and NRENs- combine to form the network that supports e-VLBI. (More detailed network diagrams for the NRENs are available in the NA2- EVN-NREN section of this report.)

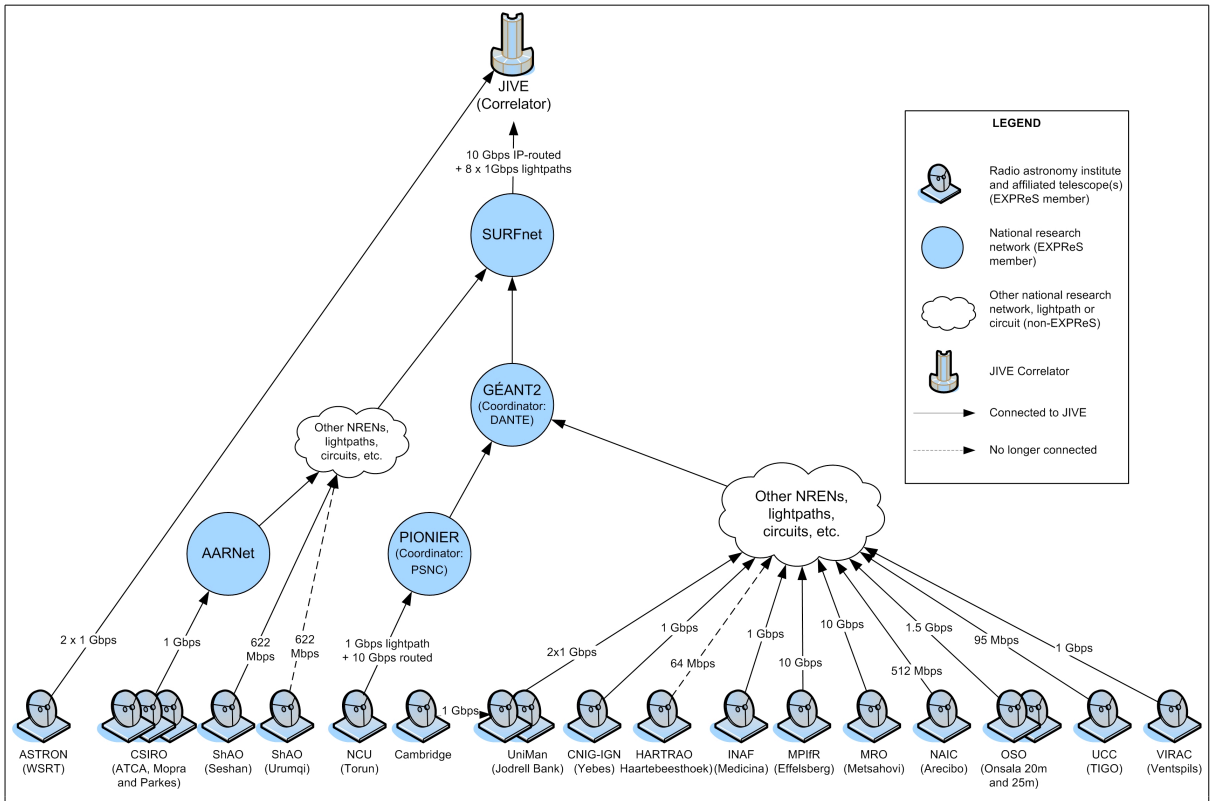


Figure: Network connections to JIVE as of end of the end of EXPReS

1.5.1.1 Activity Updates from Individual SA2 Participants

As most sites were connected in the first two years of the project, there is less incremental change to report compared to previous periods. Partners that were connected and are now operational are grouped together in a short update. Partners with specific items of note are highlighted individually.

Overall View

Arecibo, CSIRO, Effelsberg, Jodrell Bank, Medicina, Metsahovi, Onsala, Sheshan, TIGO, Torun, Westerbork and Yebes are now all connected. All of these sites are connected at 512 Mbps, with the exception of TIGO. Haartebeesthoek would be on the connected and participating list except for a telescope failure that has caused all observations to cease for an extended period.

The remaining exception on the list is Ventspils. They have been able to run network tests, but their e-VLBI system is not currently available for observation; but the network is known to be functioning quite well.

Network Backbone/Regional partners

While not part of SA2 directly, the European network backbone and NREN partners are a critical set of partners who make connection possible. These organizations are not part of SA2 in terms of funding, but they have each closely followed, assisted and supported all the activities of SA2 and EXPReS as a whole:

AARNet, DANTE, SURFnet, PSNC

1.5.2.2 SA2 Participating Institutions[18]

SURFnet provided feedback towards the end of the final period that they would not request the financial sum allocated for them in the project. The EXPReS Board took this into consideration when designing the funding allocation for the final period. Additional details are available in the NA1 section of this report.

#	Short Name	P3 Claim (EUR)[19]
1	JIVE	0.00
2	AARNet	n/a
6	ASTRON	0.00
7	CNIG-IGN	162,939.60
8	CSIRO	n/a
9	NRF	0.00
10	INAF	n/a
11	MPIfR	68,886.37
12	TKK	5,579.50
13	Cornell	382,880.00
14	UMK	12,011.93
15	OSO	5,539.81
16	ShAO	469,466.03
17	UdeC	n/a
18	UniMan	12,000.00
19	VIRAC	28,167.31
	total	1,147,470.55

[18] Participation is based on those institutions who have received funding for the activity. The Participating Institution Table assumes the following abbreviations:
P # - Participant Number

[19] Period 3 figures are based the most accurate figures available at the time of writing. Many partners were in the process of their audits and expect changes to these figures. Official figures will be provided as soon as they are available.

1.5.2.3 SA2 Deliverables and Milestones Tables

The final deliverables for SA2 are listed below.

D#	AD#	Deliverable Description	Lead			Status[20]
				D#	AD#	
129	2.06	Feasibility study of the last-mile connection to the nearest NREN node for participant HRAO	HRAO	18	20	x
130	2.14	10 Gbps link upgrade between MERLIN and JIVE	MERLIN, JIVE	18	41	4
57	2.16	Construction and equipment of the last-mile infrastructure for participant Shanghai	ShAO	21	21	4
59	2.18	Construction and equipment of the last-mile infrastructure for participant Urumqi	ShAO	21	34	4
133	2.21	Construction and equipment of the last-mile infrastructure for participant VIRAC	VIRAC	18	31	4
63	2.22	Equipment of the last-mile infrastructure for participant NAIC	NAIC	24	28	4
134	2.23	Construction and equipment of the last-mile infrastructure for participant TIGO	TIGO	18	28	4
69	2.25	Feasibility study of the last-mile connection to the nearest GÉANT node for participant INAF (Sardinia)	INAF	20	20	x
70	2.26	10 Gbps link between UniMan and OSO for ultra-VLBI tests UniMan,OSO	20	41	4	
72	2.27	e-VLBI test observations, Effelsberg	MPIfR	21	25	4
74	2.29	e-VLBI test observations, Yebes	OAN	22	38	4
86	2.3	Construction and equipment of the last-mile infrastructure for participant HartRAO	HRAO	27	27	4
97	2.31	e-VLBI test observations, Urumqi	ShAO	33	34	4
101	2.35	e-VLBI test observations, HRAO	HRAO	30	27	4
102	2.36	e-VLBI test observations, NAIC, Arecibo	NAIC	30	28	4
153	2.34	e-VLBI test observations, VIRAC (short document regarding VIRAC's inability participate in e-VLBI)	VIRAC	33	42	4
154	2.37	e-VLBI test observations, TIGO	TIGO	33	28	4
155	2.38	Construction and equipment of the last-mile infrastructure for participant INAF (Sardinia)	INAF	30	35	4

1.5.2.4 SA2 Human Resource Overview

Manpower is not claimed under SA2.

1.5.2.5 SA2 Meetings and Workshops

SA2 did not host any meetings in the final period.

[20] The status of the deliverable is tracked on a 0 to 4 scale with 0 indicating no work started and 4 indicating that the deliverable has been accepted by the project office.

1.5.2.6 SA2 Participation in External Events

The SA2 activity leader participated in the EXPReS Board and management meetings. Additionally, the SA2 leader's host institute, CNIG-IGN, hosted the weeklong NA3 end of project workshop, which is described in the NA3 section of this report.

1.6 Joint Research Activities

1.6.1 JRA1 - Future Arrays of Broadband Radio Telescopes on Internet Computing

Each of the FABRIC partners provides a short summary of their activity for the project. Detailed explanation is provided afterwards on a per-work package basis.

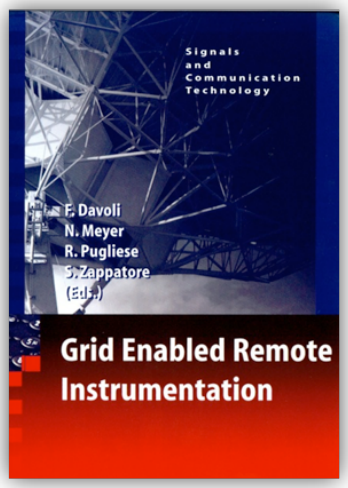
JIVE

Development and verification of the SFXC continued during the third year of the project. Many new important features were added, such as support for new input data formats and support for correlating 1-bit data. Many serious bugs were fixed as well. This resulted in the first VLBI image produced from data correlated with the software correlator. It also opened the way for integration of the software correlator into the system designed to facilitate the distributed correlation. Integration was completed during the project extension. Data was successfully correlated using two different clusters in Poznan using data transferred from JIVE and Torun.

PSNC

PSNC has focused on the creation of a first working prototype of the e-VLBI System. A prototype was deployed between JIVE and PSNC during a workshop in September 2008 (Poznań, Poland) and improved through regular teleconferences. The creation of the prototype tested the architecture design in a real working environment and facilitated certain improvements. Based on experience gained in the previous steps a final version of e-VLBI System architecture has been introduced with redesigned and improved software components. PSNC also introduced new modules which improved the functionality (e.g. the network monitoring module) of the workflow and scheduler modules. The communication protocol between software components has been standardized. The *message header* has been introduced which is attached to each SOAP message exchanged between modules. More detailed information about all activities is presented in chapters WP2.1.1 – WP2.1.3.

PSNC presented its participation in EXPReS, especially FABRIC results, at national and international conferences, workshops and meetings. PSNC has published some of the research in Computational Methods in Science and Technology.



Publications edits. By PSNC including EXPReS papers (2008 and 2009)

ASTRON

[[ASTRON did not provide an update.]]

MPIfR

An architecture for integrating future ethernet-based data acquisition hardware into the VLBI field system has been designed. A prototype has been implemented and first tests have been performed.

Metsähovi

MRO has focused on completing the design and an initial prototype of the data acquisition prototype: an IF signal sampler/packetizer into 10 Gbps Ethernet (UDP) and a 10 Gbps Ethernet (UDP) COTS recorder ("4G-EXPReS") that can use a flexible number of industry-standard Serial ATA disks. Improvements to the Tsunami protocol and software, both in speed (currently up to 7 Gbps) and in flexibility made it possible to integrate it into the "4G-EXPReS" support software. Furthermore, the Tsunami set of software (together with fuseMk5 and/or PCEVN system) is gaining widespread acceptance both in astronomical and geodetic VLBI communities of Europe, Japan, and Australia.

Onsala

Onsala focused on the higher speed aspects of the network infrastructure and how e-VLBI would take advantage of these speeds. Taking advantage of an available 10 Gbps, Onsala, with Metsahovi and Manchester, tested various layers of network stack to see how the VLBI systems operated. Additional details on the tests are provided later in the report.

Manchester

Manchester has investigated the TCP and UDP protocol performance across links both within Europe and across the Atlantic. Alongside this work, 1024 Mbps transfers over 1 Gbps light paths has been accomplished via selective packet dropping. Testing of links was done using the iBOB interfaces also used for other tests within the project. Packet level analysis (inter-packet timing at the microsecond level) was necessary to troubleshoot links.

1.6.1.1 JRA1 Activity and Status

WP 1.1.1 Data acquisition architecture (MRO)

An FPGA-based Digital Backend has been designed at MRO using a combination of an iBOB board together with an iADC A/D converter board. Dual analog IF inputs (0-512 or 512-1024 MHz) are directly digitized at 1024 Msps and with 8 bits. The samples are timestamped and processed into regular UDP packets (both unicast and multicast packets are supported) which are sent over a 10 Gbps Ethernet connection, either locally to a local data acquisition system (such as "4G-EXPReS") or remotely over the network to an off-site recipient.

The UDP packets contain user-defined headers and currently three different header variants are supported by the iBOB firmware: simple sequence number headers, Tsunami-style headers, or VDIF-compliant frame headers. A polyphase filter bank has been implemented as well but the performance is limited by the lack of internal memory of the iBOB board and its FPGA chip, thus no channelization is envisaged in the data acquisition prototype. The UDP packetization firmware, however, was disseminated to the INAF-IRA (Italy) "dBBC" digital baseband converter project to provide 10 Gbps Ethernet connectivity for its FiLa10G board.

The second major component of the data acquisition system prototype is the "4G-EXPReS" data recording and storage system capable of continuous streaming at over 4 Gbps onto a swappable module of up to 20 Serial ATA disks. This system is built entirely with commercial-off-the-shelf (COTS) components and it is useful in both traditional "ship-disks" correlation as well as near-realtime data buffering (either at telescopes or as remote recordings at the correlator). The system can be programmed to be input compatible with a low-level 10GE packet capture device (such as Mark5C) or it can equally well function as a full-fledged 10GE Network Storage Appliance (NAS).

Extensive testing of COTS hardware was required to assess e.g. the number of disks needed and the type and interface of disk controllers to guarantee performance sufficiently above 4 Gbps. For the input part of "4G-EXPReS", the original idea was to use the programmable features of the Chelsio 10 Gbps Ethernet controller board to place the incoming packets into a huge ring buffer. This would have produced a zero-processor-load 10 Gbps data reception. Unfortunately, the Chelsio chip was programmable for TCP streams only so this approach failed. However both Chelsio and Myrinet 10GE boards proved to be fast enough, reaching 4.5 Gbps using standard 1500-byte frames and more than 9 gigabits per second using jumbo frames.

For the disk streaming subsystem, the first tests were performed using twelve one-year-old 320 GB and 250 GB disks. These limited the transfer speed to the range of 3.5 Gbps. Purchasing a set of new Samsung 750 GB hard disks removed this problem, disk write speed increased 50%. The first figure shows the results of disk write speed measurements when disk controller type and the number of disks were varied as shown in the graph.

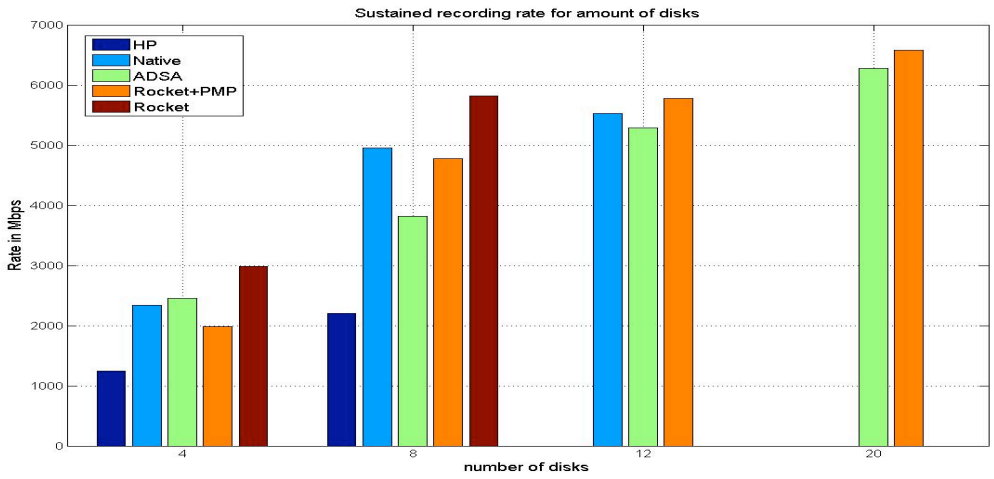


Figure: Performance on Intel X48 with SATA/SAS controllers.

The next figure illustrates the effects of using raw disks devices vs. a regular Linux XFS file system, again also with a varying number of disks. These measurements show that there are several combinations of already existing controllers, port multipliers and number of disks that are capable of delivering over 4 Gbps of streaming disk performance. Future COTS devices are bound to enhance the performance so that eventually it will be possible to reach 8 Gbps, by only upgrading COTS hardware. Full lab notes, description of hardware etc. are available at 'http://www.metsahovi.fi/en/vlbi/10gbps/'.

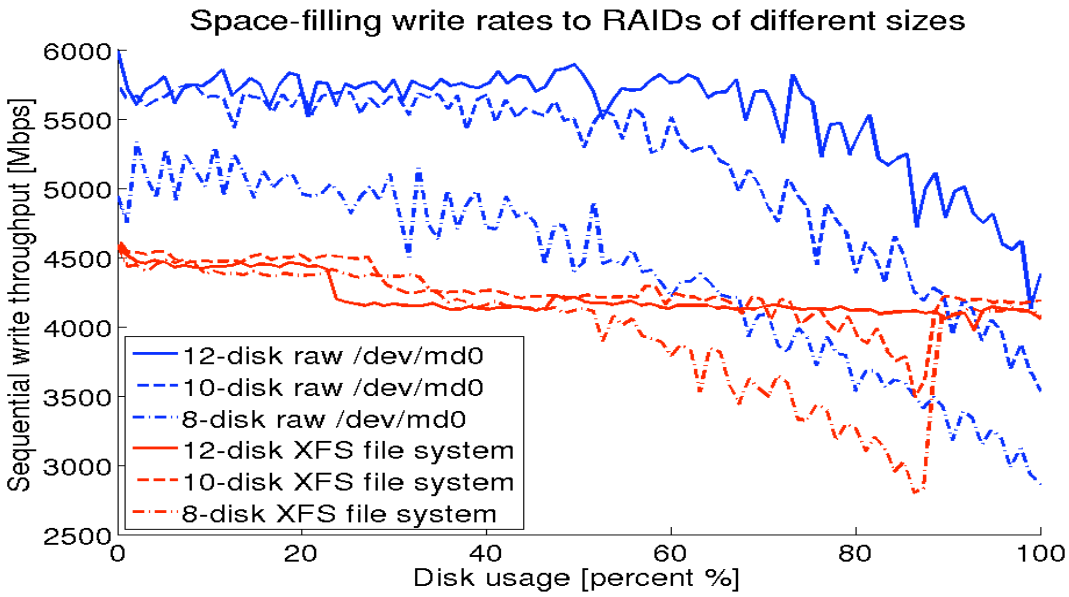


Figure: nForce 680a chipset performance in a dual Opteron AMD 2112 configuration.

Of particular interest may be the document at 'http://www.metsahovi.fi/en/vlbi/vsib-docs/mark5_upgrade' which describes the procedure MRO used to upgrade their Mark5A unit motherboard with a new one which can support both the original Conduant StreamStor disk pack controller and also the new COTS "4G-EXPReS" disk controller and 10 Gbps Ethernet boards, both at the same time. The upgrade is equally applicable to any model of Mark5 (A/B/B+/C) and this will allow smooth transitioning from the proprietary PATA disk pack technology to the more modern and fully COTS SATA disk set technology and to data rates over 4 Gbps.

When testing the combined network and disk performance it was soon realized that both UDP packet receiving and disk writing are CPU-intensive tasks. At 4 Gbps speed these tasks use fully the power of two processor cores. The test system had two dual-core processors so the CPU usage was kept on a comfortable level. Further improvement can be achieved by buying four-core processors.

It is also necessary to divide the program into several threads. The threads can then run on different cores. Fortunately Linux does this automatically, no programming effort was needed and the workload was evenly divided. Fastest transfer speeds were achieved with two six-disk RAID arrays and two different Tsunami programs. These already have two threads each. Even with a single Tsunami program a transfer rate of 4 Gbps can be sustained, see the figure below. It must be noted that these numbers include the Tsunami protocol overhead. For Mark5C-like low-level packet capture operation the speeds will be even better.

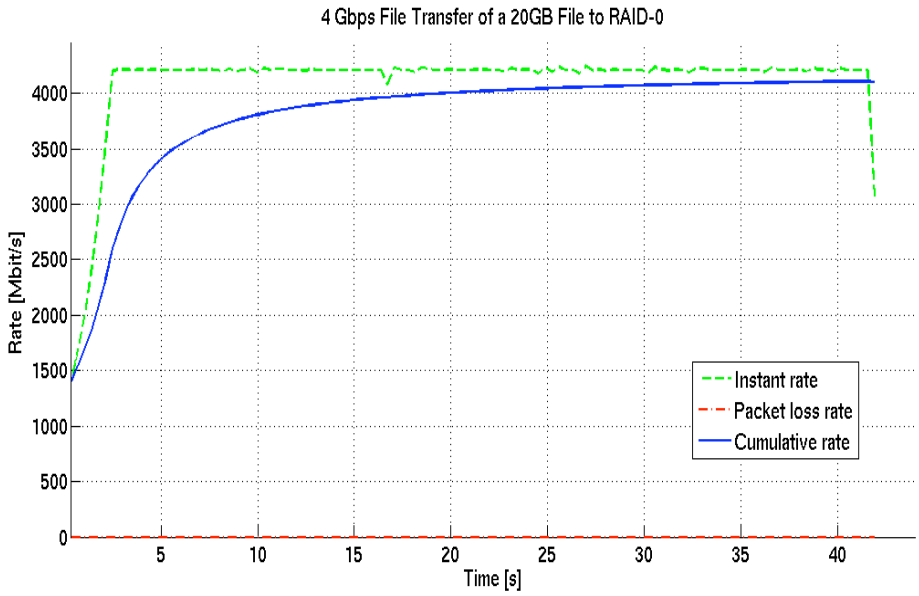


Figure: Transfer throughput for the Petabit Tsunami v1.2 transferring a 20GB file over 10G LAN to a 12-disk RAID-0 at a 4.3 Gbps target rate.

WP 1.1.2. Data acquisition prototype (MRO)

Through MRO's participation in SA2, MRO has had 10 Gbps network connectivity since 2006. The JIVE realtime e-VLBI tests up to 512 Mbps using Mark5A were performed successfully in 2007 and 2008 and reported as deliverables D73 and D131. In addition to JIVE e-VLBI, all MRO geodetic sessions that were correlated in Germany or in Japan were performed regularly either in realtime or near-realtime using Tsunami e-VLBI data transport (without shipping the disk media).

The fuseMk5A file system software (developed by Jan Wagner at MRO in period 2 of EXPReS) has been widely taken into use at many astro/geo VLBI stations and correlators and it has enabled them to do fast off-line e-VLBI by making Mark5A disk pack scans to appear as regular Linux files, ready to be transferred with Tsunami software. An updated version (also developed by Jan Wagner at MRO in period 3 of EXPReS) of this Tsunami file transfer software sustains rates up to 7 Gbps.

Realtime 4 to 8 Gbps radio signal streaming between MRO and Onsala was demonstrated with the iBOB Digital Backend prototypes in June 2008 (On-to-Mh, at 4 Gbps) and as a demo during the 7^{h} International e-VLBI Workshop held in Shanghai, China on 17th June 2008 (Mh-to-On, at 8 Gbps). The generated load on the NORDUnet network is illustrated in the two figures below. No packet loss was detected during the transfers even though no dedicated links or light paths were used, only the regular switched infrastructure of NORDUnet/GÉANT.

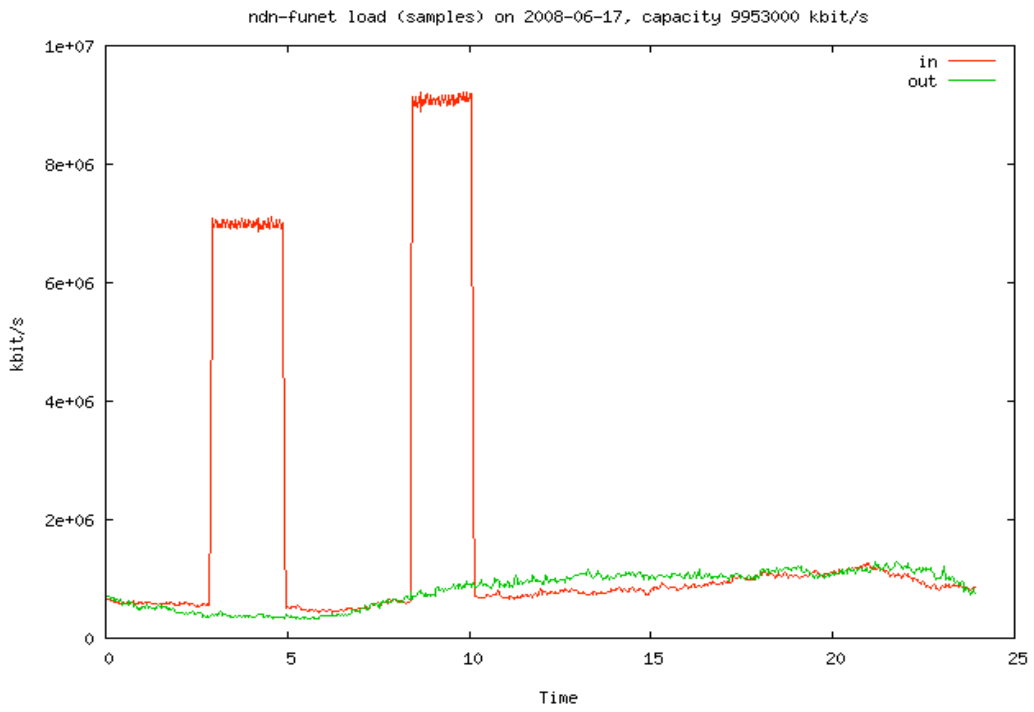


Figure: Internet 6-8 Gbps traffic between NORDUnet and Funet on one Onsala/Metsähovi 10G test day. Image © by NORDUnet 2008.

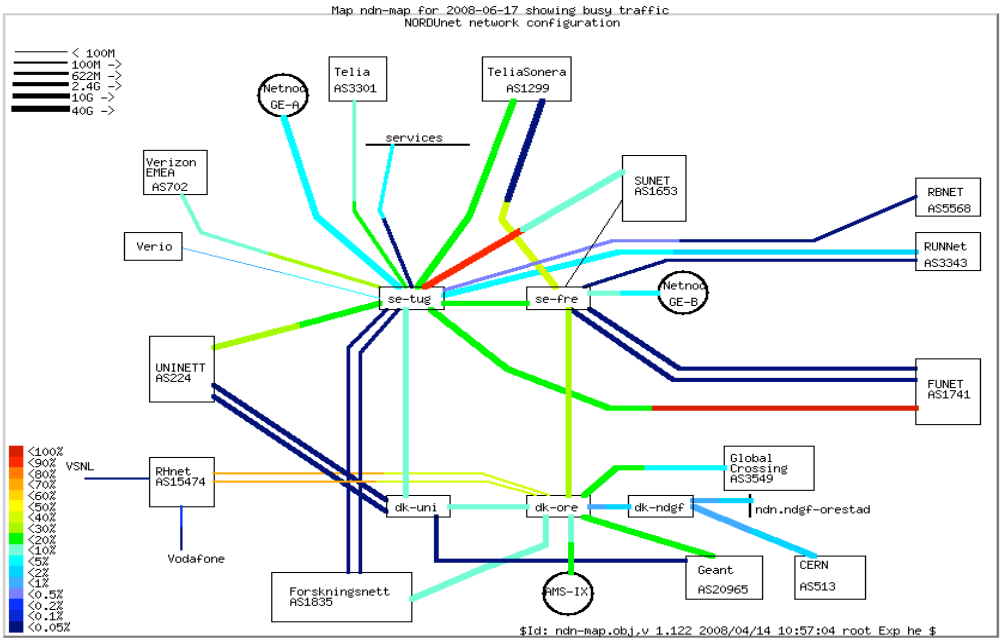


Figure: NORDUnet load map during the 8 Gbps test.
Image © by NORDUnet 2008.

The Tsunami-based UDP protocols and software developed at MRO within EXPReS are gaining popularity also outside the immediate EXPReS partners: realtime 128 and 256 Mbps observation sessions with Tsukuba, Kashima (JP), and Onsala (SE) for near realtime dUT1 estimation were performed. This technique was demonstrated live both in the JGN2 Symposium in Japan in January 2008 and in the SC08 supercomputing conference in Austin, TX, USA in November 2008 where MRO provided live data over the 10 Gbps connection directly to the NICT booth at the conference (see 'https://www2.nict.go.jp/w/w114/stsi/research/e-VLBI/SC08/SC08.html').

The near-realtime variant of the Tsunami transfer technology has recently been widely adopted with stations like Wettzell (DE), Ny Ålesund (NO), Hartebeesthoek (ZA), O'Higgins (AQ), and Medicina (IT) joining Ts/Ks/On in these quick-feedback dUT1 sessions; additionally, the Australian VLBI network uses Tsunami-based near-realtime data transfers in their PCEVN-based network.

WP 1.1.3. Data acquisition control (MPIfR)

Specifications for future data acquisition control have been worked out and described in the draft for deliverable D66. The original context has been somewhat extended in the sense that the design will allow the community to easily integrate any new ethernet-based data acquisition hardware into existing field systems. The proposed architecture will also allow true remote control of the data acquisition. A prototype system has been developed and first tests for remote control of the O'Higgins and Effelsberg stations have been performed. Work in this area is driven by a tight collaboration with the Geodetic VLBI department of the Technical University Munich (A. Neidhardt). The ideas presented in the D66 draft have been approved by E. Himwich (NASA, maintainer of the VLBI field system) and will partly enter the next field system release.

In coordination with MPIfR, MRO is striving to implement the prototype "4G-EXPReS" control software to be as compatible as possible with the Mark5C Software Interface Specification. Implementing similar VSI-S-style commands will enable common control from the Field System. An initial prototype implementation in Python of the server software has been completed.

WP 1.2.1. Broadband protocols & multicast (UniMan)

Tests on the performance of alternative protocols were completed in the summer of 2008, resulting in a comprehensive review of protocol performance. (D150). We reported on investigations on the suitability of protocols for use with high-bandwidth e-VLBI; for the transfer of high bandwidth e-VLBI data across international links and for distributed correlation. The time delay behaviour of TCP has been investigated and TCP variants have been evaluated to ascertain the benefits for real-time data transfer. A new UDP based transfer system (VLBI_UDP) has been developed, tested and portions of the code used to attain correlation at 1024Mbps over 1Gbps light paths by selective packet dropping. A new alternative protocol, DCCP, has also been studied. Measurements of throughput on trans-Atlantic links have been made with the aim of investigating possible global e-VLBI work in future. Tests of multicast techniques on both light and heavily loaded networks have been made showing that it is possible to make more efficient use of lightly loaded networks e.g. a light path.

WP 1.2.2. Broadband e-MERLIN correlator interface (UniMan)

Manchester completed tests on the performance of alternative protocols in the summer of 2008 resulting in a comprehensive review of protocol performance (D150). We reported on the suitability of protocols for use with high-bandwidth e-VLBI and on the transfer of high bandwidth e-VLBI data across international links and for distributed correlation. The time delay behavior of TCP has been investigated and TCP variants have been evaluated to ascertain the benefits for real-time data transfer. A new UDP based transfer system (VLBI_UDP) has been developed, tested and portions of the code used to attain correlation at 1024Mbps over 1Gbps light paths by selective packet dropping. A new alternative protocol, DCCP, has also been studied. Measurements of throughput on trans-Atlantic links have been made with the aim of investigating possible global e-VLBI work in future. Tests of multicast techniques on both light and heavily loaded networks have been made showing that it is possible to make more efficient use of lightly loaded networks, e.g. a light path.

This uses the same iBOB interface and VSI chip on the station boards as SA1 for multiple eMERLIN telescopes.

iBOBs have been used as network testers, where diagnostic code (a variant of UDPMon) has been implemented (iNetTest). Two iBOBs have been mounted in stand-alone equipment, with one at Onsala and one at JBO, continuously testing the link in between.

In June 2008 iBOB to iBOB tests were conducted between Onsala and Jodrell using the iNetTest firmware developed by Richard Hughes-Jones and Jonathan Hargraves. One iBOB would transmit a batch of one million 8192-byte packets spaced at 16us to produce a data rate of 4096Mbps. At the other end of the link a receive iBOB would count the packets in and generate a histogram of the arrival times between successive packets. The bursty behavior of the Alacatel TSS in Stockholm resulted in high packet loss in the 4.2 Gbps remaining light path. As a result SDH interfaces were installed and the network now runs with no packet loss at rates at or below 4.1 Gbps.

Because of the evidence of 'bunching' on the network, the iBOB which will receive the Onsala data has been modified by the addition of a 16 packet high speed buffer. The transmit and receive iBOBs have been converted to use the proposed VDIF application header format. Firmware has been developed to store a test pattern or snapshot of data in an iBOBs SRAM. This has been used to test the links to JIVE while the eMerlin correlator is being commissioned.

Meritec cables are being used to connect the iBOBs to the eMERLIN station boards. As well as maintaining compatibility with existing cabling, this solution is more flexible than using an MDR-80 ribbon cable as originally planned: inputs and outputs from different station boards can be mixed on one iBOB ZDOK connector. This will potentially allow one iBOB to export data from two station boards, reducing the number of iBOBs required. A PCB to interface the 2mm HM backplane connector to the ZDOK has been fabricated.

WP 1.2.3. Broadband test (OSO)

The transmission of 4 Gbit/s of data over shared academic networks is possible, but has the potential of impacting other users, especially since a UDP data will be used and therefore not regulate itself if faced with congestion. Onsala's pair of 1 Gbit/s links to the academic Internet was reserved for e-VLBI use. In order to support e-MERLIN and higher bandwidth e-VLBI, this link was upgraded to 10 Gbit/s in November 2007. The existing Coarse Wavelength Division Multiplexing (CWDM) equipment was replaced by Dense Wavelength Division Multiplexing (DWDM) equipment, which allowed both the original 2x 1 GE links to continue operating as before whilst adding a 10 GE link over the same fibre pair.

At the observatory, the 10 GE link is presented as a long reach fibre optic link and connects to an HP 6400cl 6-port CX-4 switch. The switch provides 6x10 gigabit CX-4 ports at the front, and a pair of X2 modular ports at the rear, one of which is populated with a 10 GE Long-Reach optic. The link runs as a dedicated lightpath between the observatory and a NORDUnet point of presence (POP) located in Stockholm, where it terminates in a Juniper MX480 router (SUNET project router in Figure 1). From this router, a routed 10 gigabit connection is available to the IP network, as well as a 10 gigabit layer 2 connection to the Alcatel Transport Service Switch (TSS) platform implemented by NORDUnet. From the TSS, layer 2 connections can be made to several destinations; currently 4 Gbit/s is allocated within the TSS to Jodrell Bank, 1.5 Gbit/s to JIVE, and 4.5 Gbit/s to LOFAR.

Data streams are directed towards a particular destination through a combination of Virtual Local Area Network (VLAN) tags (ID numbers) and IP addressing. To reach the routed IP network, or JIVE via the TSS, devices based at the observatory are assigned an IP address from a routable /29 subnet allocated by SUNET. Ethernet frames from these devices are then given a VLAN tag at the HP switch, which informs the SUNET router that these frames should be routed to the IP network. At the same time, the SUNET router examines the destination IP address, and if this is contained within the JIVE IP address space, then the frames are instead tagged with a new VLAN ID and switched into the TSS platform and onto JIVE. In this respect, the link to JIVE is a routed connection over dedicated layer 2 links. Data streams intended for any other destination within the TSS are tagged with the relevant VLAN ID at the HP switch and transparently switched into the TSS by the SUNET router.

To communicate between Onsala and Metsähovi, data is routed over the shared Nordic academic IP network infrastructure, as seen in Figure 1, at rates of up to 10 Gbit/s, dependent upon background traffic which is typically below 3 Gbit/s. For occasional testing purposes, the network operators have

agreed that we can transmit high-bandwidth UDP flows over the shared network, provided that we notify them in advance.

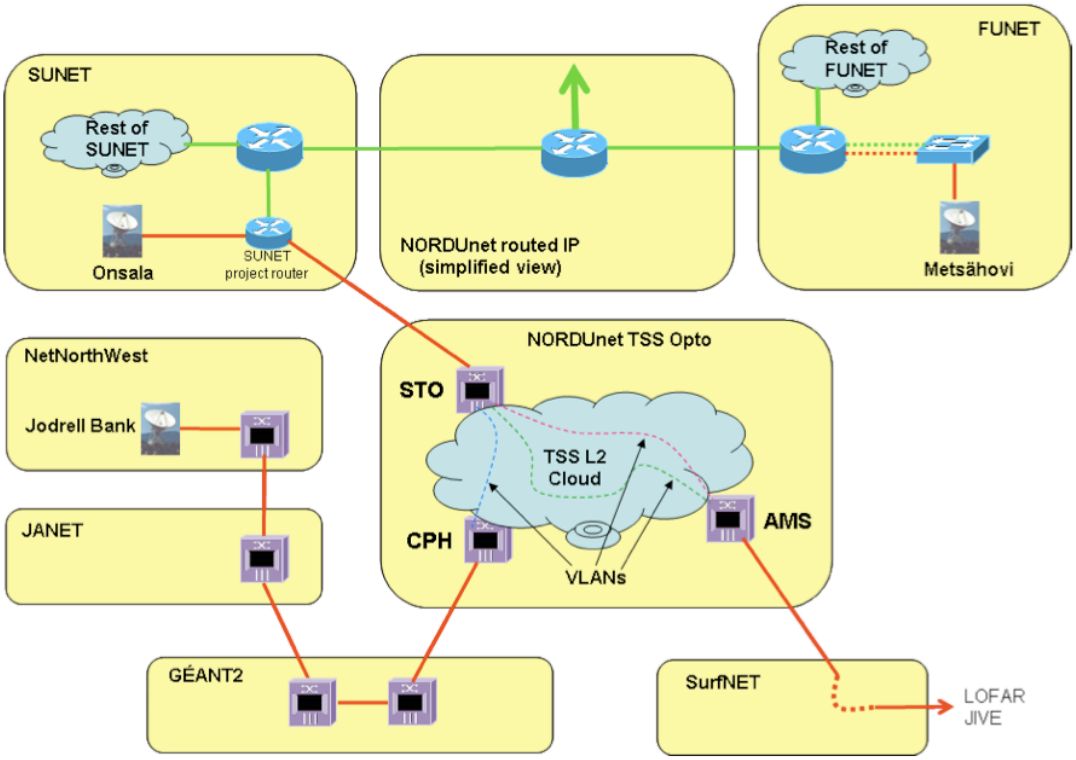


Figure: Network connectivity between Onsala and Metsähovi, LOFAR, JIVE, and Jodrell Bank.

The majority of work required for demonstrating fringes between OSO and an e-MERLIN antenna has been successfully achieved. Data can be sampled at OSO, transmitted over the network, and fed into the e-MERLIN correlator, leaving only the final correlation steps to be accomplished in order to produce OSO – e-MERLIN fringes. This has not yet been possible due to the delayed delivery of the e-MERLIN correlator, and the main priority from an e- MERLIN point of view so far has been to achieve fringes between native e-MERLIN antennas first. These have very recently been obtained, thus paving the way for fringes to Onsala, and in this respect work is still on going.

WP 1.2.4. Public to dedicated network interface (ASTRON)

[[TEXT STILL NEEDED]]

[[TEXT STILL NEEDED]]

WP 2.1.1. Grid – VLBI collaboration (PSNC)

The main goal of this activity was to design and implement a software-based distributed correlator embedded in a Grid Computing environment. The first working prototype has been designed and implemented. During the third project year, PSNC focused on creating a final design of the e-VLBI

System, based on the experience gained from building a prototype. The system architecture is presented in the figure below.

The VLBI Broker is a central module responsible for managing VLBI experiments. The VLBI Broker has been also divided into three logical subcomponents (see figure below):

- VLBI Broker core – the module core, responsible for serving all requests form other software components
- VLBI Daemon – daemon is responsible for triggering all events depending on the system state i.e. starting new experiments, updating statuses or sending notifications
- VLBI Database – internal storage for VLBI experiments

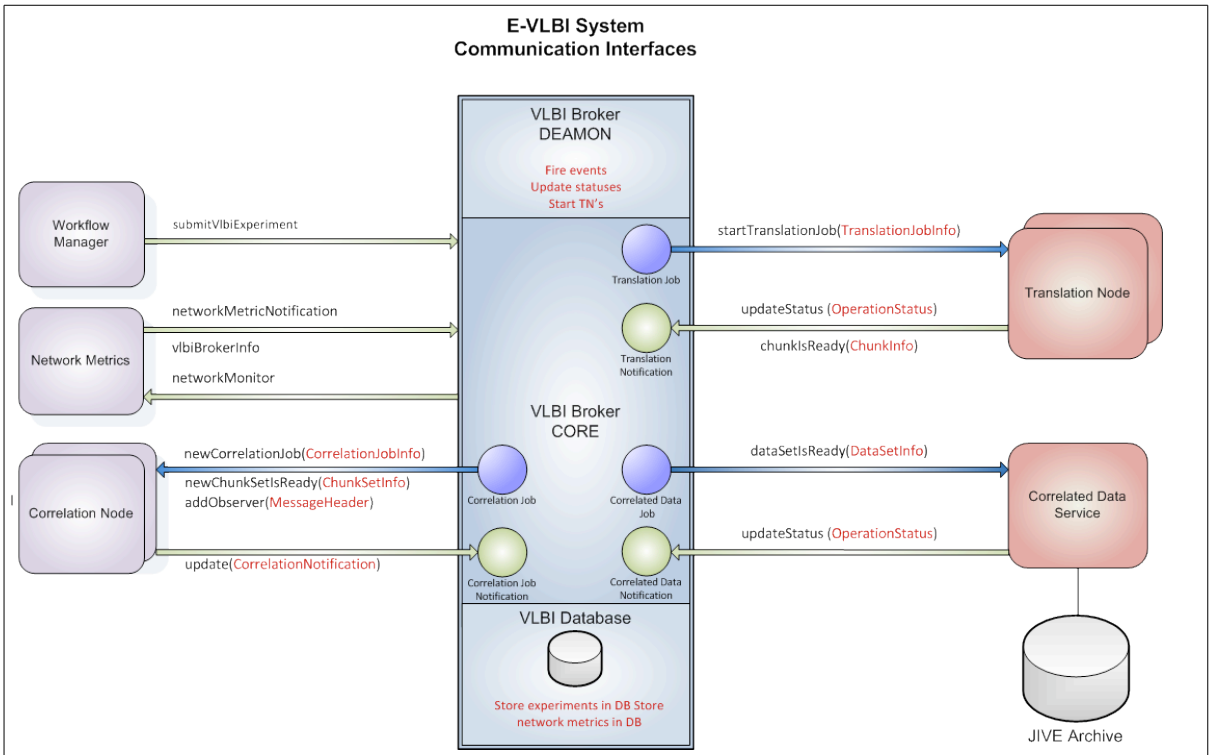


Figure: the e-VLBI System

The VLBI Broker Core has been implemented and deployed.
The broker module is a central module which communicates with other system components:

- Translation Node (TN) – responsible for handling data from radio telescopes and preparing data for correlation. There can be many TNs involved in VLBI experiment. However it is required that each radio telescope has one Translation Node assigned. The TN module is informed about new experiment by VLBI Broker.
- Network Metrics – responsible for providing best match-up of radio telescope and translation node pairs based on network measurements. The more detailed description of this module can be found at WP 2.1.3 Grid routing chapter.

- Correlation Node (CN) – was developed as a module that manages the execution of a correlation jobs on the cluster/grid. The correlation job is created based on CCF and VEX files. This is done with #newCorrelationJob web service. When the environment is prepared the Correlation Node module informs VLBI Broker that is ready to submit data chunks for correlation. Whenever a new chunk set is ready for correlation, VLBI Broker sends #newChunkSetIsReady event to CN which creates all needed configuration files and submits new correlation task. Module is checking a status of the task periodically, and when the data gets correlated, updates VLBi Broker with a location of the correlated data. The module is able to serve multiple experiments and jobs at the same time.
- Workflow Manager – graphical application for designing observation workflows and submitting them for execution in the Grid environment. The WFM application is described in more details in WP 2.1.2 chapter.
- Correlated Data Service – this service is responsible for storing correlated data in the VLBI database.

WP 2.1.2. Grid Workflow management (PSNC)

The e-VLBI system allows astronomers to plan, execute and monitor their observations in the form of so called workflows. However, the e-VLBI experiment is not only the observation itself. The e-VLBI experiment consists of a definition of storage elements, a definition of data flows or a definition of computation resources, etc. Unique e-VLBI workflows have to be created for each observation.

The Grid based approach required a different user interface than the text-based observation schedule used during experiments. The Workflow Manager Application (WFM) was created to allow users to design and execute their observation workflows more easily. Observation workflows can be created using the WFM application based on an observation schedule. An observation schedule has to be created by an astronomer on a regular basis using SCHED application. Because of the complexity of the VEX file, the e-VLBI system is based on a subset of the VEX file which contains all parameters required by the software correlation module. The parameter's set is stored in the JSON format in a file called correlator control file (CFF). The CCF file controls the behavior of the software correlator and can be edited and modified in the Workflow Manager Application.

The Workflow Manager Application has been implemented and deployed with the following functionality:

- Opening and loading a VEX file
- Converting the VEX file to the CCF file
- Definition of workflow parameters
- Definition of file servers
- Definition of correlation nodes
- Definition of data flows between components
- CCF Editor

Simple monitoring functionality is planned to be added to the WFM application to check a status of the submitted workflows.

WP 2.1.3 Grid routing (PSNC)

During the last year PSNC was working on implementation and deployment of a monitoring infrastructure for the e-VLBI System - EXPReS Network Monitor.

Network monitoring support for workflow management in GRID-enabled e-VLBI experiments has been provided with a software module which makes use of the existing and newly installed perfSONAR monitoring and measurement nodes. The open architecture of perfSONAR allows external applications to make use of data collected by the perfSONAR system through the NMWG XML schema. The measurement framework collects performance data (bandwidth utilization and Round Trip Time) using perfSONAR Command Line MP service installed in each involved domain and covering network paths between GRID computational resources.

PSNC developed the EXPReS Network Monitor to provide an optimal connection between the given EXPReS resources that should assure the fastest possible and reliable data transfer within the e-VLBI GRID environment. The module performs on-demand tests, analyses network performance along with a transporting path, and provides the information about end point pairs for e-VLBI workflow management system. Moreover it controls all configured measurements nodes, requests all needed on-demand tests, analyses the results and provides an ordered list of EXPReS resources pairs. Communication is based on the web services technology and JSON protocol. In addition it also consists of the following supporting tools deployed in each data transport resource: iperf, bandwidth test controller (BWCTL) and perfSONAR Command Line Measurement Point (CL-MP).

A session algorithm for scheduling tests and analyzing test results has been also implemented. It performs parallel measurements to reduce the number of active bandwidth tests and minimizes network load.

As a supporting infrastructure measurement server has been installed in Toruń and connected directly to PIONIER network. The server hosts measurement tools required by EXPReS Network Monitor.

WP 2.2 Combined Correlator Activities (JIVE)
WP 2.2.1 Correlator algorithm design
WP 2.2.2 Correlator computational core
WP 2.2.3 Scaled up version for clusters
WP 2.2.5 Interactive visualization
WP 2.2.6 Output definition
WP 2.2.7 Output merge

After the initial verification that was done during the third year of the project, an attempt was made to correlate a complete experiment with the goal to do a full calibration and imaging of the data and make a more thorough comparison with the output of the existing Mark4 hardware correlator.

Actual correlation took almost two weeks, partly because the small cluster used for correlation did not have enough disk space to store the uncorrelated data for the complete experiment.

Comparison of the correlated data with data produced by the Mark4hardware correlator revealed some additional problems. Correlation of multiple scans in a single correlation job didn't produce sensible results from the second scan onwards. There were still phase offsets and the amplitudes of the software correlator were much lower than the Mark4 hardware correlator produced. It took a fair amount of time to track down the bug that caused correlation of multiple scans to fail since by then the person most familiar with that code had left JIVE. The phase offsets were caused by the wrong parameters being passed to the software that calculated the correlator model. And the amplitude issues were largely caused by differences in the way the correlator output was normalized. After fixing these issues the phases produced by the software correlator matched the output from the mark4 hardware correlator very closely over the entire experiment. A small, but significant, difference in the amplitudes remains. Nevertheless the data was good enough to produce a first image.

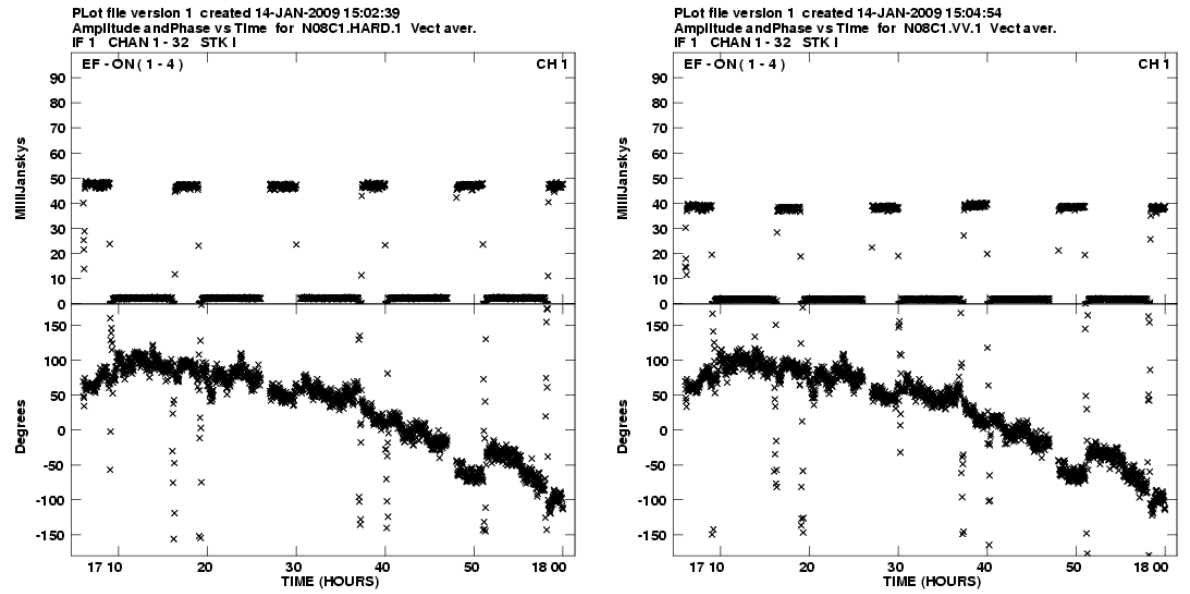


Figure X.1: Comparison of data correlated by SFXC (right) with data correlated by the MkIV hardware correlator (left) in AIPS

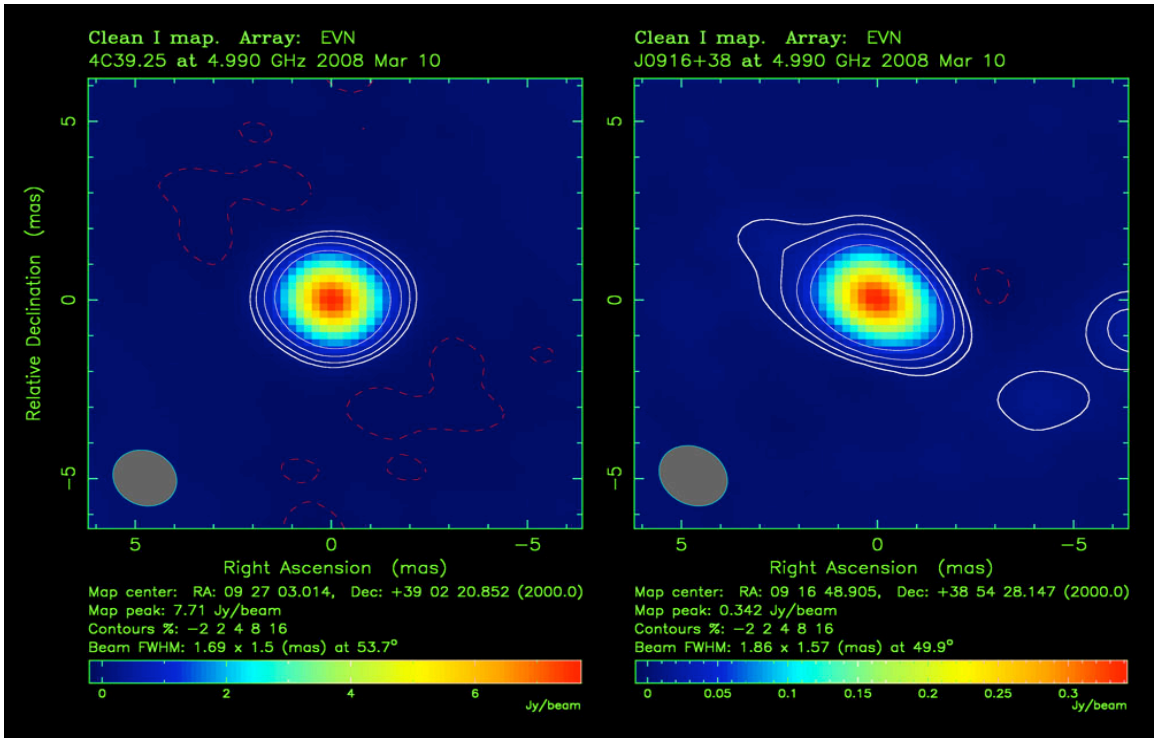


Figure X.2: First images from the SFXC software correlator. The image on the left is 4C39.25, a quasar, the image on the right is J0916+38, a somewhat weaker source.

Having gained confidence that the correlator was producing valid results, efforts started an effort to optimize the code. The algorithm used by the correlator was re-evaluated and several possible improvements were identified and implemented. Also the code was profiled extensively and several bottlenecks were identified and fixed. This resulted in a significant speedup of the correlator. But it was realized that even with this speedup, correlation of a typical VLBI observation would require hundreds of CPUs. So an effort was started to investigate if the use of GPUs (graphics cards) could be used to reduce the resources required (and therefore the amount of power required to do the processing). Work on this started in the fall of 2008 and showed that a naive attempt to just offload the FFT operations used in the algorithm to a GPU did not result in a significant speedup (less than a factor of two).

The software correlator continued to be used in the FTP fringe tests during the normal disk-based EVN sessions. These tests brought several shortcomings of the correlator to light, either in the form of bugs or missing functionality. Needless to say, all of these bugs were fixed, usually in time for the next test. Most of the missing functionality has been implemented in time for the next session. This includes the decoding of VLBA and Mark5B data formats mentioned above.

Development of the web-services designed for making the correlation was hampered by personnel issues (both at JIVE and PSNC) and interoperability issues. Some initial testing revealed issues with

the Python ZSI framework chosen to implement the web-services on the JIVE side. In particular Python's internal HTTP server lacked some functionality required by the AXIS framework used by the client written by PSNC. The decision was made to switch to a CGI based implementation using lighthhtpd.

The personnel changes on the JIVE side made it painfully obvious that using grid certificates for a project like this is very awkward. They are tied to people instead of projects or roles. So one has to go through all the loops of getting new certificates and mapping them to user accounts again whenever new people get involved. And then there is also the question on whose behalf the services should run.

Some flaws in the initial design of the system became apparent, and a face-to-face meeting in Poznan was organized to discuss the issues. Many details that had been left open were nailed down at that meeting. Initial plans for testing were also made, but unfortunately the actual testing was delayed since the VLBI broker, a key part of the system under development at PSNC wasn't ready in time.

With the assistance of the system administrators at PSNC, the software correlator itself was successfully installed on the reef cluster at PSNC. However, some issues with using the Infiniband cluster interconnect were discovered. As a temporary workaround the correlator code was modified to use the Gigabit Ethernet network which should sufficient for running small jobs.

The problems with using the Infiniband cluster interconnect were tracked down and found to be related to the on-the-fly generation of the model calculation. To circumvent the problem, the correlator was changed to use a pre-calculated model, and job scripts were modified to calculate the model before starting the correlator. Further changes were made to the protocols used by the VLBI broker in order to make commands asynchronous and to enable more useful error reporting.

The system was used successfully to correlate part of the Network Monitoring Experiment N08C1. Unfortunately the whole data flow involves copying the data up to three times. This makes I/O an important bottle-neck for the correlation process. This means that the correlation is far from real-time. Firstly, there is a significant delay before the correlated data is available for inspection. Secondly, the correlation can't keep up with the speed at which data is generated.

As part of the NWO-funded SCARIe project, in which JIVE is collaborating with the University of Amsterdam and SARA we used the software correlator in a joint demo with the GÉANT2 AutoBAHN project. In that demonstration we streamed data spread around several location across Europe and the US into the DAS-3 cluster in Amsterdam over bandwidth allocated on demand. As part of this demonstration software was written to request the bandwidth using the interfaces offered by AutoBAHN and to stream data over the negotiated circuits into the correlator. In addition some software to visualize the correlation process was written as well. The demonstrations took place at the GLIF workshop in Seattle, US and Supercomputing 08 in Austin, US.

Also within the SCARIe project we have been adding an important new capability to the software correlator: pulsar binning and gating. This capability makes it possible to observe sources that emit radio waves in regularly spaced pulses by only correlating data during the time when the source is actually "on". This functionality has been integrated but still need to be tested. Observations will be scheduled to obtain the data needed to do these tests.

Over the last year a task force has been set up to develop an international standard for a data format suitable fore-VLBI. This data format has been baptized VDIF for VLBI Data Interchange Format, and has been designed specifically with software correlation in mind. As such it will alleviate some

of the data decoding problems inherent in the data formats that are currently in use. Adaptation of this format will reduce the amount of computation that will have to be done in the correlator.

Adapting the existing source code to make efficient use of the computational power provided by modern GPU would have required substantial changes to the codebase. It was not possible to complete this effort before the end of the project.

1.6.1.2 JRA1 Participating Institutions

#	Short Name	P3 Claim (EUR)[21]
1	JIVE	226,593.48
4	PSNC	67,319.79
6	ASTRON	87,437.62
11	MPIfR	65,481.47
12	TKK	86,125.59
14	UMK	0.00
15	OSO	59,033.62
18	UniMan	50,438.02
	total	642,429.59

[21] Period 3 figures are based the most accurate figures available at the time of writing. Many partners were in the process of their audits and expect changes to these figures. Official figures will be provided as soon as they are available.

1.6.1.3 JRA1 Deliverables and Milestones Tables

D#	AD#	Deliverable Description	Lead	Delivery Month		Status[22]
				Planned	Actual	
78	1.02	Overall broadband demonstration	OSO	40	41	4
139	1.03	Visualization software (description, visualisation software)	JIVE	3842	4	
150	1.11b	Final Protocols performance report	JBO	30	36	4
43	1.13	Software data product document	JIVE	17	35	4
66	1.14	Data acquisition interface document	MPIfR	29	40	4
67	1.15	LOFAR station interface report	ASTRON	21	35	4
68	1.16	Software for workflow management (early document, 2009 Jan documentation update, tgz'd Code drop #1, tgz'd Code drop #2, additional documentation and integration report)	PSNC	18	34	4
76	1.18	Data acquisition test report	MPIfR	26		4
77	1.19	Data acquisition prototype at telescope	MRO/OSO	26	28	4
79	1.21	Software cluster correlation (sfxc-0.0.6_deliverable_2_2_3.tar.gz, First fringes announcement, code drop 2 for 2009-jan, Final e-VLBI System Report and final documentation package (tgz)	JIVE	23	35	4
87	1.23	Software to collect distributed output (PSNC report, Webservices Report, code drop)	JIVE	32	37	4
92	1.24	Software to create data product from distributed correlation	JIVE	3126	4	
93	1.25	Software routing (contained as part of tgz'd code drop #2): additional documentation and integration report	PSNC	29	34	4
105	1.26	eMERLIN interface available	JBO	30	35	4
106	1.27	Fringes with new routing	JIVE	40	37	4
108	1.28	Software distributed correlation	JIVE	33	36	4
109	1.29	First fringes Grid correlator (test and results, PSNC report, correlator software)	JIVE	40	39	4
110	1.3	First fringes on FABRIC	JIVE	35	35	4
118	1.31	Final report	JIVE	42	42	4
76a	1.32	Data acquisition interface report (combined with report for D66)	MPIfR	3640	4	
76b	1.33	Data acquisition interface report	MRO/OSO	36	32	4

1.6.1.4 JRA1 Human Resource Overview

Staff funded via EXPReS:

Name	Position Location (Short Name)	Position Description	Start Month
Helge Rottmann	MPIfR	Project scientist	21
Walter Alef	MPIfR	Staff scientist	1
Dave Graham	MPIfR	Staff scientist	1
Wagner, Jan Florian	MRO	Researcher (M. Sc. (Tech.)); Software engineer (Tsunami, Cell processor, iBOB FPGA)	1
Uunila, Minttu Maarit		Researcher (M. Sc.); Electronics engineer (deliverables, publications, hardware). 80% time with maternity leave starting 14-Nov-2008	23
Dominik Stokłosa	PSNC	IT System Analyst	2
Mateusz Pabiś	PSNC	IT System Analyst	35
Marcin Okoń	PSNC	IT System Analyst	2
Michael Sipior	JIVE	Project scientist	25
Yurii Pidopryhora	JIVE	Project Scientist	25
Hussein Ozdemir	JIVE	Project Scientist	18-25

Additional staff participating in EXPReS activities who are not directly funded via EXPReS.

Name	Position Location (Short Name)	Position Description
Bartosz Belter	PSNC	Researcher Networking Technology
Artur Binczewski	PSNC	Senior Scientist, Networking Technology
Damian Kaliszan	PSNC	Researcher Grid Technology
Marcin Lawenda	PSNC	Specialist in IT Technology
Norbert Meyer	PSNC	Distributed Computing, Head of HPC Department
Tomasz Rajtar	PSNC	Researcher Grid Technology
Szymon Trocha	PSNC	Researcher Networking Technology
Maciej Stroiński	PSNC	Networking, Technical Director
Jan Weglarz	PSNC	Resource Management, Director
Łukasz Dolata	PSNC	Network Infrastructure Analist
Mujunen, Ari Petteri	MRO	Laboratory manager (M. Sc. (Tech.))
Sergei Pogrebenko	JIVE	Development Engineer
Ritakari, Jouko Juhani	MRO	Researcher (M. Sc. (Tech.))
Molera Calvés, Guifré	MRO	Researcher (M. Sc. (Tech.)); software engineer (networking, protocols, iBOB FPGA).

1.6.1.5 JRA1 Meetings and Workshops

The below meetings are the EXPReS Sponsored meetings to which FABRIC people have attended. Please add others as appropriate.

Date Location	Meeting Title / Subject / Website Address	Number of Attendees
2008, September 1-2, Poznań	PSNC - JIVE technical meeting	8

[22] The status of the deliverable is tracked on a 0 to 4 scale with 0 indicating no work started and 4 indicating that the deliverable has been accepted by the project office.

2009, January 21, Madrid	EXPReS Fourth Board Meeting	16
2009, April 13 – May 24, Dwingeloo	PSNC and JIVE Integration workshop of e-VLBI System	3
22-26 June 2009	8th International e-VLBI Workshop, Madrid, Spain	~80
6 March 2008	PFLDNet, Manchester, UK. R. Talks by Spencer, R. and Hughes-Jones	
16-21 March 2008	Onsala and Metsahovi – discussion meeting on data aquisition systems, J. Hargreaves	
3 Aug 2008	Future e-VLBI systems (ADAPTNet) discussions, Glasgow	
4 Sep 2008	EXPReS progress meeting, Jodrell Bank, talks given by JBO and JIVE staff.	
21 Sep 2008	ECOC, Brussels, invited talk on "High Performance Optical Networks in Radio Astronomy", by R. Spencer	
22-26 Mar 2008	9th EVN Symposium, Poster on "Towards the Next Generation of e-VLBI", R. Spencer et al.	
10 Dec 2009	Electronics Knowledge Transfer Network meeting, Cambridge, talk on "Optical Fibres and Radio Astronomy", by R. Spencer	
26 Jan 2009	Fibre optics in radio astronomy: e-VLBI, eMERLIN and SKA, presentations to Photon Science director, Prof. K. Muller-Dethlefs, Manchester, (R Spencer, J. Hargreaves, R. Hughes-Jones, A. Rushton, R. McCool)	

1.6.1.6 JRA1 Participation in External Events

Date (month)	Event Description / Location
6 March 2008	PFLDNet, Manchester, UK. R. Talks by Spencer, R. and Hughes-Jones
16-21 March 2008	Onsala and Metsahovi – discussion meeting on data aquisition systems, J. Hargreaves
3 Aug 2008	Future e-VLBI systems (ADAPTNet) discussions, Glasgow
4 Sep 2008	EXPReS progress meeting, Jodrell Bank, talks given by JBO and JIVE staff.
21 Sep 2008	ECOC, Brussels, invited talk on "High Performance Optical Networks in Radio Astronomy", by R. Spencer
22-26 Mar 2008	9th EVN Symposium, Poster on "Towards the Next Generation of e-VLBI", R. Spencer et al.
10 Dec 2009	Electronics Knowledge Transfer Network meeting, Cambridge, talk on "Optical Fibres and Radio Astronomy", by R. Spencer
26 Jan 2009	Fibre optics in radio astronomy: e-VLBI, eMERLIN and SKA, presentations to Photon Science director, Prof. K. Muller-Dethlefs, Manchester, (R Spencer, J. Hargreaves, R. Hughes-Jones, A. Rushton, R. McCool)
2008 Apr 09	NORDUnet2008 / The 24th NORDUnet conference "The Biosphere of Grids and Networks", Espoo, Finland / http://www.nordu.net/conference2008/ndn2008web/home.html. MRO arranged the EXPReS project display stand to appear in the conference exhibition area.

2008 Oct 28	URSI Convention / The XXXI Finnish URSI Convention on Radio Science, Espoo, Finland / http://www.ursi.fi/2008/index.php?page=Home. Poster presentation “High capacity recorders for radio astronomy digital back-ends”, Molera G.; Wagner, J.; Ritakari, J.
2009 Jan	IYA e-VLBI <Charles: you will probably handle this in a common way?>
2008 Apr 08	INGRID 2008 / Instrumenting the Grid, Ischia, Italy / http://www.ingrid08.cnit.it/
2008 Jun 16	7th International e-VLBI Workshop, Shanghai, China / http://www.shao.ac.cn/e-VLBI2008/
2008 Sep 22	EVN TOG / EVN Technical and Operations Group, Bologna, Italy / http://www.ira.inaf.it/meetings/evn9/tog/
2008 Nov 24	RadioNet / The 8th Radio Net Engineering Forum Workshop / Upgrading the Horizon: New Radiotelescopes and Instrumentation for Astronomy and Geodetic Technology, Yebes, Spain / http://www.radionet-eu.org/rnwiki/UpgradingtheHorizon
2008 Apr 9-11	"Workflow management in Remote Instrumentation Infrastructure - based on e-VLBI experiences" Dominik Stokłosa, INGRID 2008, Ischia, Italy
2009 Jun 26	"e-VLBI with the SFXC correlator", Madrid, Spain,
2009 Jun 26	"The latest tests of the SFXC correlator", Madrid, Spain

2. List of Deliverables

The following table covers deliverables for the final 18 month period, sorted by activity and then by AD#. Deliverables for the project were reported and recorded via the project wiki at <http://www.jive.nl/dokuwiki/doku.php/expres:management:deliverables2>, deliverables presented during the first two periods are not included in this table, but are available via the project wiki. The table below is taken from the wiki, and represents a subset of the information available online. For example, footnotes indicating movement in the planned delivery date have been removed to provide clarity to the table.

With this document is a hard copy of all of the deliverables in the below table. For some deliverables, multiple items were necessary to fulfill the requirements, for example, a written document along with the compressed source code for a piece of software. Some large documents were provided to fulfill the requirements of more than one deliverable, particularly for deliverables that began to become highly linked in their development. These details are described in the wiki as well as on the cover sheets of the deliverables.

In the table, the planned and actual delivery dates are given in terms of project month. Deliverable status was recorded in the project on a 0 to 4 scale, with 4 indicating completed deliverable. The nature column is describes the type of deliverable using the following abbreviations:

R = Report;
P = Prototype
D = Demonstrator
O = Other

The dissemination level is described with the following abbreviations:

PU = Public
PP = Restricted to other programme participants (including the Commission Services).
RE = Restricted to a group specified by the consortium (including the Commission Services).
CO = Confidential, only for members of the consortium (including the Commission Services).

D#	Lead	A	AD#	Descrip	Plan	Actual	Status	Nature	DisLev
111	JIVE	NA	1.03	Annual report (incl. Financial information) to EC	42	42	4	R	PP
112	JIVE	NA	1.04	Final Report to Board and EC	42	42	4	R	PP
113	JIVE	NA	1.05	Final Plan for using and disseminating knowledge	42	42	4	R	PP

D#	Lead	A	AD#	Descrip	Plan	Actual	Status	Nature	DisLev
114	JIVE	NA	1.06	Implementation of the Gender Action Plan	42	42	4	R	PP
115	JIVE	NA	1.07	Raising public participation and awareness	42	42	4	R	PU
200	JIVE	NA	1.08	Month 42 Report (including financial information to EC)	42	42	4	R	PU
88	DANTE	NA	2.05	EVN-NREN meeting No. 3 (with Madrid meeting) (slides for the EVN NREN meeting are posted on the meeting's website, scroll down to Thu 25 June 2009)	40	40	4	R	PP
89	DANTE	NA	2.06	EVN-NREN representatives present EXPReS networking results at the e-VLBI Science & Technology Workshop (slides for the EVN NREN meeting are posted on the meeting's website)	40	40	4	R	PU
116	DANTE	NA	2.07	NA2 annual & Final reports	42	42	4	R	PP
91	OSO	NA	3.03	eVSAG meeting No. 3	40	40	4	R	PP
94	OSO	NA	3.04	e-VLBI Workshop to be held in Madrid (workshop website)	40	40	4	O	PU
107	JIVE	NA	3.05	Publication of e-VLBI Workshop proceedings (POS online proceedings)	42	42	4	R	PU
83	JIVE	NA	4.06	e-VLBI Demonstration and attendance at Network events (months 13-24)	24	18	x	O	PU
117	JIVE	NA	4.07	e-VLBI Demonstration and attendance at network events (months 25-42)	36	30	x	O	PU
12	JIVE	SA	1.03	Fast/adaptive scheduling tools: Dynamic scheduling of the e-EVN	36	36	4	D	PU
27	JBO	SA	1.04	eMERLIN VSI interfaces design	22	41	4	P	PU
36	JIVE	SA	1.07	Monitored information handling modules	42	42	4	D	PU
45	JBO	SA	1.09	Tests using local Jodrell Bank home e-MERLIN telescope	22	41	4	D	PU
52	JBO	SA	1.14	Test using remote e-MERLIN telescope	24	41	4	D	PU
53	JIVE	SA	1.16	VSI support software (Gzipped tarfile of modified SU control code, Controlling the Mark5B playback unit from JCCS, Domino: Mark5B control software	28	38	4	D	PU
85	JBO	SA	1.19	Multiple e-MERLIN telescope tests	24	41	4	D	PU
95	o/s	SA	1.2	Improved network applications (tarball of locally developed Mark5 control code, jive5a history and download page)	27	30	4	D	PU

D#	Lead	A	AD#	Descrip	Plan	Actual	Status	Nature	DisLev
126	JIVE	SA	1.23	Use of WSRT synthesis data for e-VLBI calibration	17	22	4	R	PU
127	o/s	SA	1.24	Mark5A code modifications (OS and application upgrade, from Debian Sarge to Debian Etch with SDK8.1, jive5a history and download page)	27	30	4		
128	o/s	SA	1.25	Mark5B code modifications (tarball of locally developed Mark5 control code, Domino: Mark5B control software)	27	31	4		
151	JIVE	SA	1.28	On-the-fly fringe fitting (On-the-fly clock searching)	28	28	4		
152	JIVE	SA	1.29	Real-time download and extraction of station information: Monitoring the EVN via Field System logfiles	30	32	4		
156	JIVE	SA	1.30	Automatic diagonal weight detection, Automated correlator diagnostics	33	41	4		
162	JIVE	SA	1.32	Enhancements & additions to real-time pipeline: Enhancements to the easyJIVE web-driven post-processor tool	42	42	4		
163	JIVE	SA	1.33	Enhancements & additions to existing monitoring tools: Extensions to the Data Status Monitor tool	42	41	4		
166	JIVE	SA	1.34	Mixed-mode operations: Tarball of locally developed Mark5 control code	38	35	4		
167	JIVE	SA	1.35	1024 Mbps e-VLBI and beyond (e-VLBI beyond the 1Gb/s speedbump, Throughput plot of e-VLBI run on October 19 2008, with the Effelsberg, Jodrell Bank and Westerbork radio telescopes transmitting data at a full 1024 Mbps, Metsahovi four-Gbps data recorder for VLBI and eVLBI, iBob data acquisition and network streaming)	40	36	4		
129	HRAO	SA	2.06	Feasibility study of the last-mile connection to the nearest NREN node for participant HRAO	18	20	x	R	PU
130	MERLIN,JIVE	SA	2.14	10 Gbps link upgrade between MERLIN and JIVE	18	41	4	O	PU
57	ShAO	SA	2.16	Construction and equipment of the last-mile infrastructure for participant Shanghai	21	21	4	O	PU
59	ShAO	SA	2.18	Construction and equipment of the last-mile infrastructure for participant Urumqi	21	34	4	O	PU
133	VIRAC	SA	2.21	Construction and equipment of the last-mile infrastructure for participant VIRAC	18	31	4	O	PU
63	NAIC	SA	2.22	Equipment of the last-mile infrastructure for participant NAIC	24	28	4	O	PU

D#	Lead	A	AD#	Descrip	Plan	Actual	Status	Nature	DisLev
134	TIGO	SA	2.23	Construction and equipment of the last-mile infrastructure for participant TIGO	18	28	4	O	PU
69	INAF	SA	2.25	Feasibility study of the last-mile connection to the nearest GÉANT node for participant INAF (Sardinia)	20	20	x	R	PU
70	UniMan,OSO	SA	2.26	10 Gbps link between UniMan and OSO for ultra-VLBI tests	20	41	4	O	PU
72	MPIfR	SA	2.27	e-VLBI test observations, Effelsberg	21	25	4	R	PU
74	OAN	SA	2.29	e-VLBI test observations, Yebes	22	38	4	R	PU
86	HRAO	SA	2.30	Construction and equipment of the last-mile infrastructure for participant HartRAO	27	27	4	O	PU
97	ShAO	SA	2.31	e-VLBI test observations, Urumqi	33	34	4	R	PU
153	VIRAC	SA	2.34	e-VLBI test observations, VIRAC	33	42	4	R	PU
101	HRAO	SA	2.35	e-VLBI test observations, HRAO	30	27	4	R	PU
102	NAIC	SA	2.36	e-VLBI test observations, NAIC, Arecibo	30	28	4	R	PU
154	TIGO	SA	2.37	e-VLBI test observations, TIGO	33	28	4	R	PU
155	INAF	SA	2.38	Construction and equipment of the last-mile infrastructure for participant INAF (Sardinia)	30	35	4	O	PU
78	OSO	J	1.02	Overall broadband demonstration	40	41	4	D	PU
139	JIVE	J	1.03	Visualization software (description, visualisation software)	38	42	4	P	PU
150	JBO	J	1.11b	Final Protocols performance report	30	36	4		
43	JIVE	J	1.13	Software data product document	17	35	4	P	PU
66	MPIfR	J	1.14	Data acquisition interface document	29	40	4	R	PU
67	ASTRON	J	1.15	LOFAR station interface report	21	35	4	R	PU
68	PSNC	J	1.16	Software for workflow management (early document, 2009 Jan documentation update, tgz'd Code drop #1, tgz'd Code drop #2, additional documentation and integration report)	18	34	4	P	PU
76	MPIfR	J	1.18	Data acquisition test report	26		4	R	PU

D#	Lead	A	AD#	Descrip	Plan	Actual	Status	Nature	DisLev
77	MRO/ OSO	J	1.19	Data acquisition prototype at telescope	26	28	4	P	PU
79	JIVE	J	1.21	Software cluster correlation (sfxc-0.0.6_deliverable_2_2_3.tar.gz, First fringes announcement, code drop 2 for 2009-jan, Final e-VLBI System Report and final documentation package (tgz)	23	35	4	P	PU
87	JIVE	J	1.23	Software to collect distributed output (PSNC report, Webservices Report, code drop)	32	37	4	P	PU
92	JIVE	J	1.24	Software to create data product from distributed correlation	31	26	4	P	PU
93	PSNC	J	1.25	Software routing (contained as part of tgz'd code drop #2): additional documentation and integration report	29	34	4	P	PU
105	JBO	J	1.26	eMERLIN interface available	30	35	4	P	PU
106	JIVE	J	1.27	Fringes with new routing	40	37	4	D	PU
108	JIVE	J	1.28	Software distributed correlation	33	36	4	P	PU
109	JIVE	J	1.29	First fringes Grid correlator (test and results, PSNC report, correlator software)	40	39	4	D	PU
110	JIVE	J	1.30	First fringes on FABRIC	35	35	4	D	PU
118	JIVE	J	1.31	Final report	42	42	4	R	PU
76a	MPIfR	J	1.32	Data acquisition interface report (combined with report for D66)	36	40	4		
76b	MRO/ OSO	J	1.33	Data acquisition interface report	36	32	4		

3. Use and Dissemination of Knowledge

3.1 Activity Updates

Combined NA Update

The use and dissemination of knowledge is fundamental to the ongoing success and impact of EXPReS. The NA sections have a particular responsibility as their primary focus is ensuring the wider use of EXPReS. In support of this, the NAs have organized a comprehensive set of avenues through which information about the project is shared.

The widest reaching tool used is the internet. EXPReS has set up a general project web site at <http://www.expres-eu.org/> to describe the project and highlight activities. In addition, more specific information is available from the project wiki at <http://www.jive.nl/dokuwiki/doku.php/expres:expres>. The wiki allows project participants to add and change information about the project's progress dynamically. Most of the wiki is freely viewable by the public (drafts and documents with sensitive information such as IP addresses are not publicly available). Only registered users are allowed to edit pages.

NA2 and NA3 have as their primary deliverables meetings which are designed to exchange information within the community. The EVN-NREN and eVSAG meetings have been held through the project's duration. Additionally, NA members participated in external meetings where they talked about and described EXPReS.

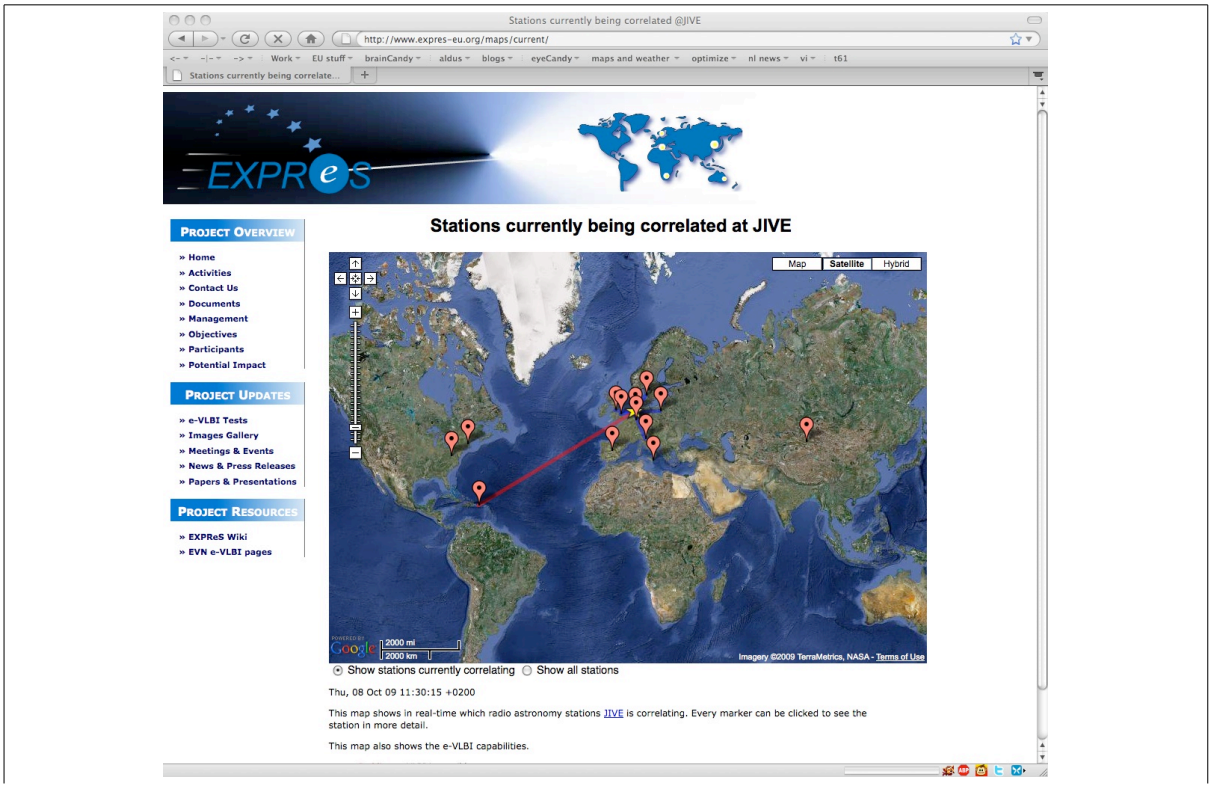


Figure: Webpage showing the real-time correlation status.

The NAs do not generally produce scientific publications. However, NA4 is specifically tasked with publishing brochures and physical materials for the project as a whole. The first EXPReS brochure was published early in 2007 and copies were distributed to all partners for further dissemination at meetings and to the astronomy and network communities. Supporting materials are planned for the upcoming year. Via NA4, additional tools which will continue to be used after the life of the project were also made available. On the webpage, the real-time correlation display is active and linked both internally and by multiple outside organizations (see figure above).

EXPReS is spreading information and experience as the members are participating in various other astronomy bodies, most notably those of the EVN. Key EXPReS personnel have functions in the EVN PC, TOG and its board. Close links exists with other EC funded projects like RadioNet and SKADS, as well as MC training programs like ANGLES and ESTRELA. There is also participation in network centric projects such as ESLEA and RINGRID.

Combined SA Update

The most fundamental way in which the capabilities of and results from e-VLBI are spread through the community is by the regular and consistent scheduling of e-VLBI observations within the EVN. e-VLBI has become a regular observing mode and is now part of every call for observation. This call is one of the most widely distributed pieces of text within the VLBI community and is one of the most likely to be noticed by other astronomers who might have research interest in the radio spectrum.

As reported, SA1 has continued to present EXPReS and e-VLBI at a large number of conferences and workshops over the past 18 months. Several Astronomers Telegrams were published, illustrating the newly found power of e-VLBI to generate immediate and scientifically relevant results. The e-VLBI demonstrations culminated at the opening of the International Year of Astronomy and during the IYA outreach programme, the “100 hours of astronomy”, which reached a very large world-wide audience.

Awareness of the new capabilities and scientific opportunities that are being offered are spreading in the community and beyond, which has resulted in a marked increase of proposals, both regular and target of opportunity.

JRA Update

The JRA activity combines the efforts of astronomers, network engineers and computer scientists, and is in some ways, an outreach effort due to its simple existence. In the final period of the project, the collaboration between the parties helped to identify some of the deeper assumptions that all sides held about their own actions and approaches.

Looking beyond the project, most of the activity partners have provided text for outreach materials, newsletters and press releases (e.g., Metsähovi has provided input for many EVN newsletters). In conjunction with the International Year of Astronomy, project partners Metsähovi, PSNC and JIVE provided localized versions of many of the materials.

Many partners have created posters and other materials that have helped increase the exposure of EXPReS. In addition to the shared use of the EXPReS display, PSNC highlighted EXPReS at several conferences (ISC2008 conference , June 200; Supercomputing 2008, Nov. 2008, Austin, USA).

3.2 Publications

3.2.1 NA Publications (combined)

Date	Description
Mar 2009	Press release from JIVE. European VLBI Network to participate in "100 Hours of Astronomy" with live webcast and e-VLBI observations
Jan 2009	Press release from JIVE. Marathon e-VLBI images, educational e-VLBI Web site and Virtual Radio Interferometer now available online
Jan 2009	Press release from JIVE. Radio-astronomers conduct marathon observation with world-sized telescope. A series of additional press releases were created by partners based on the initial release, see below: * AARNET press release; AARNET demonstrates value in developing the digital economy * ASTRON press release; The Westerbork Radio Telescope participates in marathon observation * CSIRO press release; CSIRO telescopes lead observing marathon * DANTE press release; GÉANT2 network enables global real-time radio astronomy project * Jodrell Bank press release; Radio-astronomers conduct marathon observation with telescope the size of the Earth * NICT press release; Participation in virtual astronomical observation by world radio telescopes connected with high speed internet (Japanese) * OSO press release; Radio-astronomers conduct marathon observation with world-sized telescope (PDF) * SHAO press release; The Shanghai Radio Telescope participates in marathon observation (English, Chinese) * TIGO press release; Radioastrónomos conducen maratónica observación con telescopio del tamaño del planeta (PDF) (Spanish) * UTAS press release; UTAS helping global space venture (PDF)
Dec 2008	Press release from JIVE. SKA identified as an essential facility for the future of European astronomy (ASTRON)
Nov 2008	Press release from JIVE. Effelsberg telescope inaugurated as member of the e-VLBI network
May 2008	Press release from JIVE and DANTE: http://www.geant2.net/server/show/ConWebDoc.2805. “GÉANT2 network helps create real-time virtual telescope 11,000 km in diameter”
May 2008	Press release from JIVE. Networks create 11,000km real-time virtual telescope. A series of additional press releases were created by partners based on the initial release, see below: * Science/astronomy version; EXPReS conducts first real-time e-VLBI observation with telescopes in Africa, Europe, North America and South America * DANTE press release; GÉANT2 network helps create real-time virtual telescope 11,000 km in diameter * Hartebeesthoek news; Four Continent e-VLBI with HartRAO
May 2008	Hito en la conectividad de Concepcion a Europa, Primeras observaciones e-VLBI en el Observatorio Geodesico TIGO (TIGO) (PDF)

May 2008	Press release from JIVE. e-VLBI with HartRAO (HartRAO)
Apr 2008	Press release from JIVE. Effelsberg joins the e-EVN. A series of additional press releases were created by partners based on the initial release, see below:
May 2008	Press release from JIVE and DANTE: http://www.geant2.net/server/show/ConWebDoc.2805 "GÉANT2 network helps create real-time virtual telescope 11,000 km in diameter" * MPIfR press release; The largest synthesized telescope in Europe doubles its surface (English / German)

The following list includes the refereed science publications

Pub #	Description
1	Albert, J., Aliu, E., Anderhub, H. et al. (2008): Multi-wavelength (radio, X-ray and gamma-ray) observations of the gamma-ray binary LS I +61 303, Astropys. J., Vol. 684, p. 1351 (arXiv:0801.3150)
2	Jozsa, G.I.G., Garrett, M.A., Oosterloo, T.A., Rampadarath, H., Paragi, Z., van Arkel, H., Lintott, C., Keel, W.C., Schawinski, K., Edmondson, E. (2009): Revealing Hanny's Voorwerp: radio observations of IC 2497 (Astronomy and Astrophysics, accepted)
3	Paragi Z., Trejo A., Giacani E., Dubner G., Bykov A.M., Langevelde, H.J. (2008): The compact radio counterpart of IGR J20187+4041 near the flaring source AGL 2021+4029 and 3EG J2020+4017, Proceedings of Science, PoS(MQW7)105
4	Paragi, Z. (2008): Real-Time VLBI Observations of Compact Objects in: Observational Evidence for Black Holes In the Universe, ed. Chakrabarti S.K., American Institute of Physics (AIP, NY), Volume 1053, pp. 383-386
5	Paragi, Z., Csizmadia, Sz., Borkovits, T., Mosoni, L., Sturmann, L., Abraham, P., Garrett M.A. (2008): CHARA and e-VLBI observations of Algol, Proceedings of Science, PoS(MRU)122
6	Rushton, A., Bach, U., Spencer, R., Kadler, M., Church, M., Balucinska-Church, M., Wilms, J., Hanke, M., Zola, S., Schulz, N. (2008): Cygnus X-2 in a radio quiet state, ATel #2052
7	Trejo, A., Giacani, E., Paragi, Z., Langevelde, H.J., Dubner, G., Bykov, A.M. (2008): VLBI observations of the radio counterpart of IGR J20187+4041/2MASX J20183871+4041003 in the error box of the gamma-ray source AGL2021+4029/3EG J2020+4017, ATel #1597
8	Tudose, V., Miller-Jones, J.C.A., Fender, R.P., Paragi, Z., Sakari, C., Szostek, A., Garrett, M.A., Dhawan, V., Spencer, R.E., van der Klis, M., Rushton, A. (2009): Probing the behaviour of the X-ray binary Cygnus X-3 with very-long-baseline radio interferometry (will be submitted to MNRAS soon)
9	Tudose, V., Paragi, Z., Fender, R., Spencer, R., Garrett, M., Rushton, A. (2008): e-VLBI observations of Cyg X-3, ATel #1476
10	Tudose, V., Paragi, Z., Soleri, P., Russell, D.M., Maitra, D., Lewis, F., Fender, R.P., Garrett, M.A., Spencer, R.E., Rushton, A. (2009): e-EVN observations of Aql X-1 in outburst, ATel #2000
11	Tudose, V., Paragi, Z., Trushkin, S., Soleri, P., Fender, R., Garrett, M., Spencer, R., Rushton, A., Burgess, P., Kunert-Bajraszewska, M., Pazderski, E., Borkowski, K., Hammargren, R., Lindqvist, M., Maccaferri, G. (2008): e-VLBI observations of SS 433 in outburst, ATel #1836

In addition to the above papers, there are close to 10 papers that are in preparation, in the refereeing process or awaiting publication that can not yet be announced.

3.2.2 SA Publications (combined)

Date	Description
Sept 2008	EXPReS and the e-EVN. Szomoru, A. Proceedings of the 9th European VLBI Network Symposium on The role of VLBI in the Golden Age for Radio Astronomy and EVN Users Meeting. September 23-26, 2008. Bologna, Italy. Online at http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=72, p.40. Publication Date: 00/2008

3.2.3 JRA Publications (combined)

Pub #	Description
1	Springer, 2008. p. 571 Okon, M.; Stoklosa, D.; Oerlemans, R.; Langevelde, H.J. van; Kaliszan, D.; Lawenda, M.; Rajtar, T.; Meyer, N.; and Stroinski, M. "Grid Integration of Future Arrays of Broadband Radio-Telescopes moving towards e-VLBI." Grid Enabled Remote Instrumentation. Springer, 2008. p. 571. (Fig. below)
2	CMST Volume 15(1) 2009 "The User Interaction and Workflow Management in Grid enabled e-VLBI Experiments", Ł. Dolata, M. Okoń, D. Stokłosa, Sz. Trocha, N. Meyer, M. Stroiński, D. Kaliszan, T. Rajtar, M. Lawenda, Computational Methods In Science and Technology Volume 15(1) 2009 (Fig. below)
3	Nothnagel, A.; Bertarini, A.; Dulfer, C.; Artz, T.; Wagner, J.; Molera, G.; Ritakari, J. "Comparisons of correlations using disk-transfer and e-VLBI-transfer" in "Measuring the Future", Proceedings of the Fifth IVS General Meeting, pp. 63-67, 2008, ISBN 978-5-02-025332-2
4	Wagner, J.; Molera, G.; Uunila, M. "High Bandwidth Data Acquisition and Network Streaming in VLBI" Proceedings of the Instrumenting the Grid (InGrid) 2008 Workshop, Lacco Ameno, Island of Ischia, Italy, 2008, (to appear in 2009)

3.3 Presentations

3.3.1 NA Presentations (combined)

Date	Description
June 2009	Richard Hughes-Jones, DANTE "Development of Real Time e-VLBI at Jodrell Bank Observatory
Nov 2008	T. Charles Yun . "EXPReS: Operationalizing e-VLBI." ICT 2008, Lyon, France
Jun 2008	T. Charles Yun, "EXPReS - Real-time VLBI - The current status and next steps." AOGS 2008 (Asia Oceania Geosciences Society), Pusan, Korea.
Jun 2008	T. Charles Yun, "EXPReS - e-VLBI activities in Europe." KVN: Korea VLBI Network Headquarters, Seoul, Korea.
Jun 2008	John Chevers. The ORIENT, TEIN and GEANT projects: international research networks. 7th International e-VLBI Workshop, Shanghai, China

3.3.2 SA Presentations (combined)

Date	Description

April 2008	A. Szomoru, “Radio Astronomy in the era of high-speed networks”, STOA/TERENA Workshop, Brussels, Belgium
April 2008	P. Boven, “e-VLBI Networking Challenges”, NORDUnet 2008, Espoo, Finland
May 2008	Z. Paragi, "e-EVN and VSOP-2", VSOP-2 Technical Meeting, Bonn, Germany
May 2008	H. J. van Langevelde, “e-EVN: a real-time telescope larger than Europe”, Terena Networking Conference, Bruges, Belgium
May 2008	A. Szomoru, “SA1: Production e-VLBI service”, EXPReS Annual Review, Brussels, Belgium
June 2008	Z. Paragi, "WSRT for EVN amplitude and polarization calibration, and for triggering transients", WSRT users meeting, Amersfoort, The Netherlands
June 2008	P. Boven, “e-VLBI beyond the 1Gb/s speedbump”, 7th International e-VLBI Workshop, Shanghai, China
June 2008	R. Hughes-Jones, “4 Gigabit Onsala - Jodrell lightpath for e-VLBI - The iNet test unit - Development of real time e-VLBI at Jodrell Bank Observatory”, 7th International e-VLBI Workshop, Shanghai, China
June 2008	Z. Paragi, “e-EVN science projects (2006-2008)”, 7th International e-VLBI Workshop, Shanghai, China
June 2008	A. Szomoru, “EXPReS and the e-EVN”, 7th International e-VLBI Workshop, Shanghai, China
June 2008	H. Verkouter, “The road to 980Mbps e-VLBI”, 7th International e-VLBI Workshop, , Shanghai, China
June 2008	J. Wagner, “iBOB data acquisition and network streaming”, 7th International e-VLBI Workshop, Shanghai, China
Aug 2008	H. J. van Langevelde, “e-VLBI: a real-time telescope of intercontinental dimensions”, 2008 URSI General Assembly, Chicago, USA
Sep 2008	R. Spencer, "High Performance Networks in Radio Astronomy", ECOC2008, Brussels, Belgium
Sep 2008	R. Spencer, "ADAPTNET - The Future is wide", EXPReS meeting, Jodrell Bank, UK
Sep 2008	R. Hughes-Jones and J. Hargreaves, "4 Gigabit Onsla-Jodrell Lightpath for e-VLBI - The iNET test unit", EXPReS meeting, Jodrell Bank, UK
Sep 2008	A. Szomoru, "Recent e-EVN Developments", EXPReS meeting, Jodrell Bank, UK
Sep 2008	J. Hargreaves "e-MERLIN Data Import and Export", EXPReS meeting, Jodrell Bank, UK
Sep 2008	A. Szomoru, “EVN/JIVE technical developments”, TOG meeting, Bologna, Italy
Sep 2008	D. Small, “Dynamic scheduling of the e-EVN: a progress report”, TOG meeting, Bologna, Italy
Sep 2008	Z. Paragi, "Type Ib/c supernovae with the EVN", 9th European VLBI Network Symposium, Bologna, Italy
Sep 2008	A. Szomoru, “EXPReS and the e-EVN”, 9th International European VLBI Symposium, Bologna, Italy
Sep 2008	R. Spencer, R. Hughes-Jones and D. Simeonidou "Towards the Next Generation of e-VLBI", 9th International European VLBI Symposium, Bologna, Italy
Sep 2008	Z. Paragi, "Experience with e-VLBI (from a user's perspective)", EVN Users meeting, Bologna, Italy
Oct 2008	A. Szomoru, “e-VLBI: real-time radio astronomy”, 8th Annual GLIF Workshop, Seattle, USA
Nov 2008	R. Spencer "Optical Fibres and Radio Astronomy" Jodrell Bank Symposium, Jodrell Bank, UK
Nov 2008	A. Szomoru, “EXPReS and the e-EVN”, EVN Science Day, Arecibo, Puerto Rico
Dec 2008	R. Spencer "Challenges for the Data Network", Electronics Knowledge Transfer Network workshop on SKA, Cambridge, UK

Dec 2008	P. Boven, “International Lightpath Experiences”, TERENA E2E Workshop, Amsterdam, The Netherlands
April 2009	A. Szomoru, “EVN/JIVE Technical Developments”, TOG meeting, Torun, Poland
April 2009	Z. Paragi, "The e-EVN: a realtime VLBI instrument", European Week of Astronomy and Space Science (JENAM), Hatfield, United Kingdom
April 2009	Z. Paragi, "e-EVN and global VLBI observations of SN 2007gr", European Week of Astronomy and Space Science (JENAM), Hatfield, United Kingdom
May 2009	A. Szomoru, “e-EVN Update”, EVN Board Meeting, Gothenburg, Sweden
June 2009	P. Boven, "Worldwide Networking for e-VLBI", TNC2009, Malaga, Spain
June 2009	R. Hughes-Jones and J. Hargreaves "Commissioning and Using the 4 Gigabit Lightpath from Onsala to Jodrell Bank", 8th International e-VLBI Workshop, Madrid, Spain
June 2009	R. Hughes-Jones and J. Hargreaves, "iNetTest a 10 Gigabit Ethernet Test Unit", 8th International e-VLBI Workshop, Madrid, Spain
June 2009	R. Spencer "Progress and Status of e-MERLIN", 8th International e-VLBI Workshop, Madrid, Spain
June 2009	A. Szomoru, “e-EVN Progress, 3 years of EXPReS”, 8th International e-VLBI Workshop, Madrid, Spain
June 2009	Z. Paragi, "A suspected Dark Lens revealed with the e-EVN", 8th International e-VLBI Workshop, Madrid, Spain
June 2009	P. Boven, 'e-VLBI Networking Tricks", 8th International e-VLBI Workshop, Madrid, Spain
July 2009	Z. Paragi, "Very Long Baseline Interferometry (VLBI) in the 'golden age' of radio astronomy", 1st School on Multiwavelength Astronomy, Paris, France

3.3.3 JRA Presentations (combined)

Date	Description
April 2008	"Workflow management in Remote Instrumentation Infrastructure - based on e-VLBI experiences" Dominik Stokłosa, INGRID 2008, Ischia, Italy
June 2008	Jouko Ritakari (coauthors Wagner, J.; Molera, G.) “Metsähovi Four-Gbps Data Recorder for VLBI and e-VLBI” Session 2 of the 7th International e-VLBI Workshop in Shanghai, China http://202.127.29.4/e-VLBI2008/presentation/JoukoRitakari.pdf
June 2008	Guifré Molera (coauthors Wagner, J.; Ritakari, J.) “Evaluation of new multi-bits sampling systems” Session 3 of the 7th International e-VLBI Workshop in Shanghai, China
June 2008	Jan Wagner (coauthors Ritakari, J.; Molera, G.) “iBOB data acquisition and network streaming” Session 3 of the 7th International e-VLBI Workshop in Shanghai, China http://202.127.29.4/e-VLBI2008/presentation/JanWagner.ppt
Sep 2008	Jouko Ritakari “8-Gbps e-VLBI howto” EVN TOG Meeting, Bologna, Italy
Nov 2008	Guifré Molera (coauthors J. Wagner, J. Ritakari) “High capacity recorders at 4 Gbps” The 8th RadioNet Engineering Workshop, Yebes, Spain http://www.radionet-eu.org/rnwiki/UpgradingtheHorizonPresentations?action=AttachFile&do=get&target=molera.pdf

Nov 2008	Jouko Ritakari (coauthors J. Wagner, G. Molera) "Metsähovi four-Gbps recorder and it's applications" The 8th RadioNet Engineering Workshop, Yebes, Spain http://www.radionet-eu.org/rnwiki/UpgradingtheHorizonPresentations?action=AttachFile&do=get&target=ritakari.pdf
Nov 2008	Jan Wagner (coauthors S. Pogrebenko, G. Molera, M. Uunila, J. Ritakari, A. Mujunen, M. Avruch, L. Gurvits) "Evaluation of new high-performance spectrometer and spacecraft tracking software", poster presentation The 8th RadioNet Engineering Workshop, Yebes, Spain http://www.radionet-eu.org/rnwiki/UpgradingtheHorizonPresentations?action=AttachFile&do=get&target=wagner.pdf
Nov. 2008	General presentation, Supercomputing 2008, Austin, USA, Norbert Meyer
Nov. 2008-March 2009	Presentations at regional workshops and events (City Hall, Board of Users, Norbert Meyer

4. Annexes

4.1 Summaries from the Fourth EXPReS Board Meeting

Meeting Details

The Fourth EXPReS Board Meeting was held Wednesday 21 January 2009 in Madrid, Spain, hosted by our partners CNIG-IGN.

Meeting Participation

Present	
Bachiller, Rafael	CHIG-IGN
Colomer, Paco	CNIG-IGN
Hase, Hayo	BKG-TIGO
Langevelde van, Huib	JIVE
Marecki, Andrzej	CfA
Mujunen, Ari,	MRO
Smelds, Ivars	VIRAC
Spencer, Ralph	JBO
Szomoru, Arpad	JIVE
Tzioumis, Tasso, chair	CSIRO
Vos de, Marco	ASTRON
Yun, Charles	JIVE
Zensus, Anton	MPifR

Visitors:	
Rottmann, Izabela	MPifR
Stoklosa, Dominik	PSNC

Apologies for absence:	
Benvenuti, Piero	INAF
Booth, Roy	HARTRAO
Campbell, Don	NAIC/CORNELL
Conway, John	OSO
Davies, Dai	DANTE
Hancock, Chris	AARNet

Hong, Xiaoyu	SHAO
Kus, Andrzej	NCU/UMK
Meyer, Norbert	PSNC
Neggers, Kees	SURFnet
Zagars, Juris	VIRAC

Represented:	
AARNet	By Tasso Tzioumis, CSIRO
DANTE	By Ralph Spencer, JBO
NCU-UMK	By Andrzej Marecki, CfA
PSNC	By Dominik Stoklosa, PSNC
SHAO	By Paco Colomer, CHIG-IGN
SURFnet	By Huib van Langevelde, JIVE
VIRAC	By Ivars Smelds, VIRAC

Summary

In total 15 individuals were present at the meeting with seven partners represented bia proxy. Minutes were taken by Yvonne Kool and are available on the project wiki.

During the meeting, each of the project activities provided updates since the previous board meeting. The Board commented and decided on several items associated with the budget process and project reporting. The end of project science meeting was formulated as a week long workshop with proceedings.

4.2 Software Code Deliverables

Some of the EXPReS deliverables are the source code used to compile applications used during the correlation process. Much of this software is run in a fairly specific and unique environment; it is not a general purpose application that can be run on any computer. The software deliverables are thus provided as source code in the format that is common to exchange between our developers and software engineers in general. The "tar" files (often again compressed with gzip, bzip2) are available via the wiki and are not included in the printed report.

4.3 DVD with digital copies of this report

A DVD containing a copy of this report, the deliverables and associated materials is attached with this report. An ISO image of the entire DVD is also being made available for download on the wiki. We have made an attempt to provide documents in neutral file formats (PDF and OpenOffice) where possible.

Deliverables without sensitive information are also available on the project wiki for general viewing. Sensitive files are available in the password protected portion of the wiki. If you would like access to that section, please send an email to the Project Coordination Office.

4.4 Timeline diagrams from previous periods

In the introduction, a timeline for the previous 18 month periods was provided. Similar diagrams were presented for the Period 1 and Period 2 reports and are included here as references.

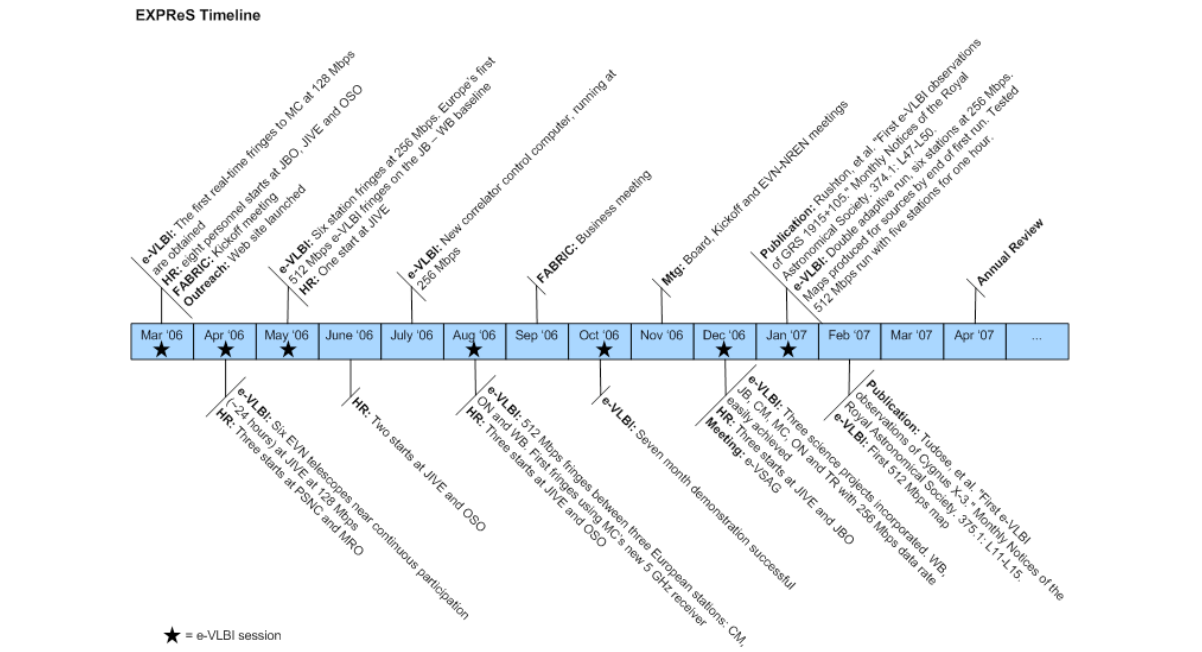


Figure: Period 1 timeline

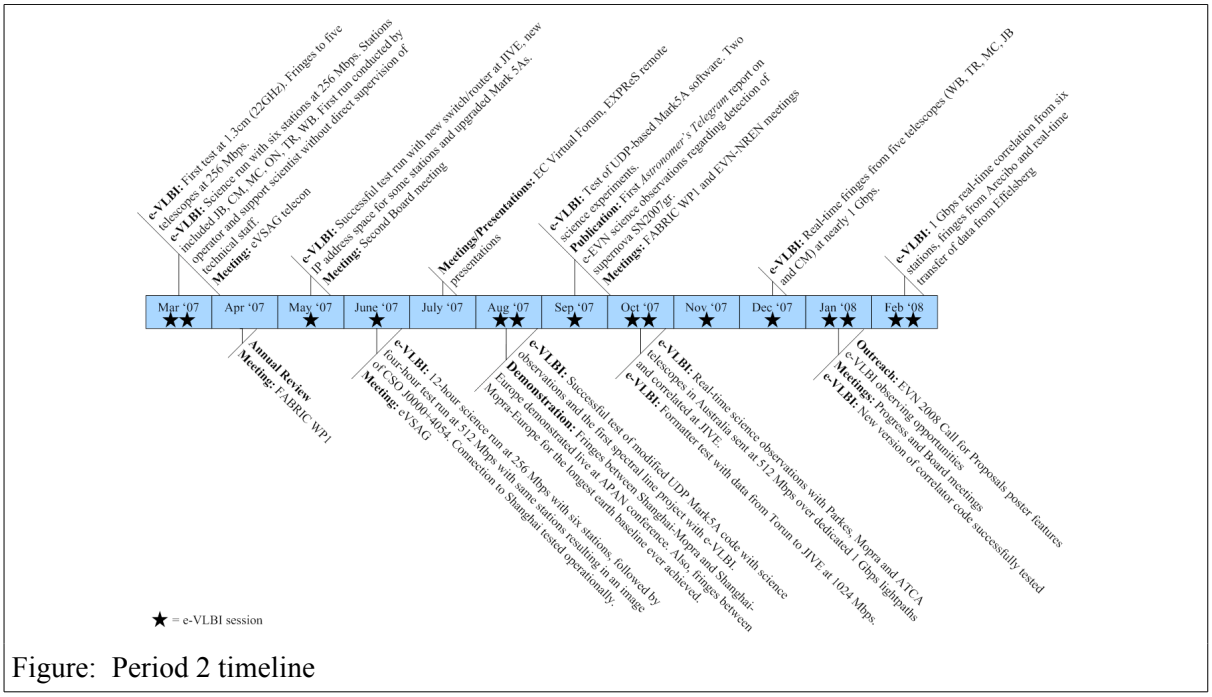


Figure: Period 2 timeline

4.5 Glossary of Terms

The following glossary comes from the project wiki <http://www.jive.nl/dokuwiki/doku.php/expres:glossary> and has been compiled over the duration of the project. We hope that most unfamiliar terms in the document will be covered here.

a	AARNet- Australia's Academic and Research Network
	AGN- Active Galactic Nuclei
	AIPS- Astronomical Image Processing System
	ALBUS- Advanced Long Baseline User Software
	ANGLES- Astrophysics Network for Galaxy LEnsing Studies
	ANTAB- File containing aprioiri station calibration information, used in AIPS
	ANTABFS- “Raw” version of ANTAB
	ASTRON- Netherlands Foundation for Research in Astronomy
	ATCA- Australia Telescope Compact Array
	ATNF- Australia Telescope National Facility
b	BBC- BaseBand Converter
	BL-Lac- BL Lacertae
	Bwctl- Bandwith Test Controller
c	CALC- Program to compute the apriori geometric delay-model
	CAS- Chinese Academy of Sciences
	CASA- Common Astronomy Software Applications
	C-band 5 GHz observing band
	CCC- Correlator Control Computer
	CeNTIE- Centre for Networking Technologies for the Information Economy
	CfA- Center for Astrophysics (Cambridge, MA, USA)
	CJF- Caltech-Jodrell Flat spectrum Survey
	Cm-* baseline- Cambridge-to-all-stations baseline
	COSMIC- Continuous Single-disc Monitoring of Intra-day variability at Ceduna
	CPU- Central Processor Unit
	CSIRO- Commonwealth Scientific and Industrial Research Organisation
	CSO- Compact Symmetric Object
d	Da-* baseline- Darnhall-to-all-stations baseline
	DANTE- Delivery of Advanced Network Technology for Europe
	DEMON- Dark Matter and Dark Energy

	DEVOS- Deep Extragalactic VLBI-Optical Survey
	DFG- German Science Foundation
	DPU- Data Playback Unit
	DXRBS- Deep X-ray Radio Blazar Survey
e	EADS- European Aeronautic Defence and Space Company
	EADS LIFE- EADS Lunar Infrastructure For Exploration
	EC - European Commission
	EGRET- Energetic Gamma Ray Experiment Telescope
	ERI- EVN Reliability Indicator
	ESA- European Space Agency
	eSMA- Extended SubMillimeter Array
	ESTRELA- Early-Stage TRaining site for European Long-wavelength Astronomy
	EU- European Union
	e-VLBI- electronic VLBI
	EVN- European VLBI Network
	EXPReS- Express Production Real-Time e-VLBI Service
f	FABRIC- Future Arrays of Broadband Radio-telescopes on Internet Computing
	FIRST- VLA Faint Images of the Radio Sky at Twenty-one Cm
	FITS- Flexible Image Transport Systems
	FP6- Framework Programme 6
	FPGA- Field Programmable Gate Array
	FTP- File Transfer Protocol
g	GARR- Gestione Ampliamento Rete Ricerca (Italian Academic and Research Network)
	GB- Gigabyte
	Gbps- Gigabit per second
	GBT- Green Bank Telescope
	GÉANT- Pan-European Gigabit Research and Education Network
	GeV- Giga-electron-Volt
	GMRT- Giant Metre-wave Radio Telescope
	GPS- Global Positioning System
	GPS- GHz-Peaked-Spectrum
	GSFC- Goddard Space Flight Center
h	HDF-N- Hubble Deep Field - North

	HFF- Hubble Flanking Field
	HSA- High Sensitivity Array
i	I/O- Input/Output
	IAA- International Academy of Astronautics
	IDV- intra-day variability
	IERS- International Earth Rotation Service
	IGN- Instituto Geografico Nacional (Spain)
	INAF- Istituto Nazionale di Astropisica (Italy)
	IRA- Istituto di Radioastronomia (Italy)
	IRAM- Institut de Radio Astronomie Milimetrique
	ISM- Interstellar Medium
	ISS- interstellar scintillation
	IVS- International VLBI Service
j	Jb1+2- Jodrell Bank telescopes 1 + 2
	JBO- Jodrell Bank Observatory (UK)
	JCCS- JIVE Correlator Control Software
	JCMT- James Clerk Maxwell Telescope (Hawaii, USA)
	JIVE- Joint Institute for VLBI in Europe
	JPL- Jet Propulsion Laboratory
k	K-band - 22 GHz observing band
l	LAN- Local Area Network
	LBA- Australian Long Baseline Array
	L-band - 1,6 GHz observing band
	LOFAR- Low Frequency Array
	LTO- Linear Tape Open (tape backup system)
m	Mk5- Mark 5 (PC based disk recording system)
	MASIV- MicroArcsecond Scintillation-Induced Variability
	MB- Megabyte
	Mbps- Megabit per second
	MERLIN- Multi-Element Radio Linked Interferometer Network
	MHz- Mega Herz
	MIM- minimum ionosphere model
	MPIfR- Max Planck Institut für Radioastronomie (Germany)

	MTU- Maximum Transmission Unit
n	NA- Networking Activity
	NAOC- National Astronomical Observatory of China
	NASA- National Aeronautics and Space Administration
	NICT- National Institute of Information & Communications Technology (Japan)
	NME- Network Monitoring Experiment
	NOT- Nordic Optical Telescope
	NRAO- National Radio Astronomy Observatory (USA)
	NREN- National Research and Education Network
	NWO- Nederlandse Organisatie voor Wetenschappelijk Onderzoek
o	OAN- Observatorio Astronomico Nacional
	OSO- Onsala Space Observatory (Sweden)
p	PC-EVN- disk-based recording format
	PCInt- Post-Correlator Integrator
	PERT- Performance Enhancement and Response Team
	PI- Principal Investigator
	PoP- Point of Presence
	PPARC- Particle Physics and Astronomy Research Council (UK)
	PSNC- Poznan Supercomputing and Networking Center
q	
r	RFI- Radio Frequency Interference
	ROEN- North-eastern Space Radio Observatory
	ROSAT- Röntgen Satellite
	ROT (clocks) Reconstituted Observing Time
	RuG- University of Groningen
s	SARA- Dutch National Computer Centre
	SCARIe- Software Correlator Architecture Research and Implementation for e-VLBI
	SCHED- VLBI Scheduling Software, developed by NRAO
	SCUBA- Submillimetre Common-User Bolometer Array
	SFXC- Software FX correlator
	SHAO- Shanghai Astronomical Observatory (China)
	SKA- Square Kilometer Array
	SKADS- SKA Design Study

	Smart-1- Small missions for Advanced Research in Technology
	SPIE- International Society for Optical Engineering
	SURFNet- Dutch Research Organisation
t	TB- Terabyte
	TeV - Tera-electron-Volt
	TIGO- Transportable Integrated Geodatic Observatory
	TNA- Trans National Access
	TRM- Track Recovery Module
u	UAO- Urumqi Astronomical Observatory (China)
	ULX- Ultra-Luminous X-ray Sources
	UTC- Coordinated Universal Time
	UvA- University of Amsterdam
	UVW- Coordinate system for the visibility data as measured by an interferometric arary
v	VC- Video Channel
	VLA- Very Large Array
	VLBA- Very Long Baseline Array
	VLBEER- EVN schedule server
	VLBI- Very Long Baseline Interferometry
	VSOP- VLBI Space Observatory Programme
w	WSRT- Westerbork Synthesis Radio Telescope (Netherlands)
x	
z	