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PREPARATION OF THE VIRAC RADIO TELESCOPE RT-32 FOR E-VLBI OBSERVATIONS

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Abstract. Fully steerable parabolic antenna RT-32, with the mirror diameter 32 m owned by Ventspils International Radioastronomy Centre (VIRAC) is available for fundamental and applied research in the field of radio astronomy. The RT-32 is fitted with the receiving systems for the frequency range 327 MHz to 12 GHz installed and tuned. A set of recording equipment has been assembled, which allows recording the signal into two channels with a bandwidth up to 1 GHz in each channel. The recording system provides a high stability of the time frame, which is prerequisite for the Very Long Baseline Interferometry (VLBI) observations.

In the year 2012 VIRAC staff made preparations of the RT-32 data receiving systems and network infrastructure for the work in the e-VLBI mode. Results of these efforts were tested with Torun observatory, and later in the EVN e-VLBI observation session at 5 GHz. Experiments have shown that the RT-32 is able to observe at frequency range 5 GHz and transfer data in the e-VLBI mode with data speed rate up to 1 Gbps.

The current status of the RT-32, the availability of its receiving and data acquisition units for e-VLBI observations and the results of the conducted e-VLBI observational experiments are discussed.

Key words: EVN, VLBI, e-VLBI, radioastronomy, Irbene, data acquisition system, receiver

1. INTRODUCTION

The technique, known as Very Long Baseline Interferometry (VLBI), since it was first demonstrated in 1967, widely used for studies of a jets and an associated phenomena around compact object such as those in an active galactic nuclei, a molecular clouds, a star forming regions and transient events such as a X-ray binary flares. The interferometer receiving elements (telescopes) are independent with no direct link circuit, unlike ordinary radio interferometer. This allows to incorporate multiple radio telescopes located hundreds or thousands of kilometres apart and produce an images with milliarcsecond resolution (Taylor et al. (1999)).

One of the most sensitive VLBI array in the world is European VLBI Network (EVN), an interferometric array of the radio telescopes spread throughout Europe and far beyond. Presently, more than 25 individual antennas are participated in the VLBI sessions organized by EVN in which are included some of the world's largest and the most sensitive radio telescopes such as Effelsberg (the diameter D=100 m) and Lovell Telescope (D=76 m). In addition to "EVN-only" observations, the EVN array often links-up with MERLIN, an interferometer network of telescopes distributed around the southern half of the UK, Very Long Baseline Array (VLBA) and independent antennas from Russia, China and South Africa forming so-called "global VLBI" array. This array is thus sensitive to a wide range of radio structures from the arcsecond scale to the sub-milliarcsecond scale at frequencies higher than 5 GHz (van Langevelde (2010)).

Quality of the maps obtained by the interferometer array depends on the amount of u,v plane data available, which in turn depends on the number of baselines forming by antenna pairs. (Felli & Spencer (1989)). Therefore, extending of the EVN network with an additional radiotelescope like the Irbene RT-32 improves performance of whole array. In Figure 1 depicted u,v plane coverage of EVN network obtained from the observation of source 0234+285, in the e-VLBI experiment EG069C (described in the section 3.1), the red dots are representing the baselines formed by Irbene and nine EVN stations.

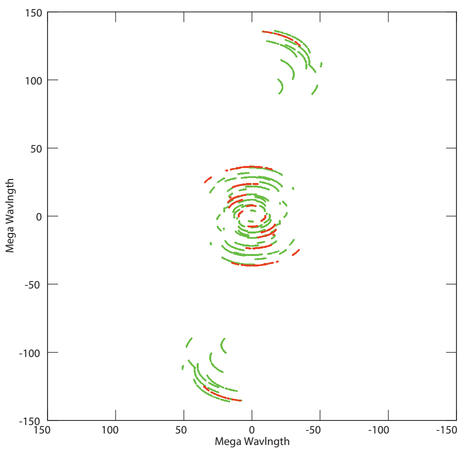

Fig. 1. The u–v plane coverage of EVN network (Megawavelengths) obtained from the observation of source 0234+285, in the e-VLBI experiment EG069C, by red dots are marked the baselines formed by the RT-32 radiotelescope

The EVN manage an observations for 3 periods per year known as "VLBI sessions". Each of these sessions is approximately 3 - 4 weeks long and typically involve 3 - 4 different observing frequencies. After VLBI session stations participated in EVN send the disk packs of observed data to the correlation centre located in the Joint Institute for VLBI in Europe (JIVE)[1]. Accordingly, results of the observations are emerged only by a few weeks. Motivation of such a time consuming procedure is the rather large amount of the raw VLBI data measured in TB per station. However, the substantial progress of the data communication network quality and increment of the bandwidth is reached during the last decades, allows to directly link the radio astronomy observatories with VLBI data correlation centre with the data rates 1 Gbps up to 10 Gbps. This has enabled to conduct so-called e-VLBI observations (Campbell (2010)).

[1]European VLBI network homepage http://www.evlbi.org/

e-VLBI, or electronic Very Long Baseline Interferometry, uses a fibre optic networks to link EVN radio telescopes to the JIVE central data processor, which correlates the data from the telescopes in real-time. Therefore, it allows immediately to identify and correct problems during an observation by an operators in each observatory. At the same time, the astronomers can obtain and inspect their results in time of hours rather than weeks compared to the classic VLBI. e-VLBI is the obvious choice for studies of transient events such as a supernova explosions and a gamma-ray bursts; follow-on observations can be triggered in time, also in other spectral regions. But the advantage of e-VLBI is not only to get results faster, but also it is easier to organize. Currently, EVN organize several e-VLBI sessions per month and in a future it might become the standard way of doing VLBI.

In Figure 2 model of communications used for e-VLBI connections is pressented.

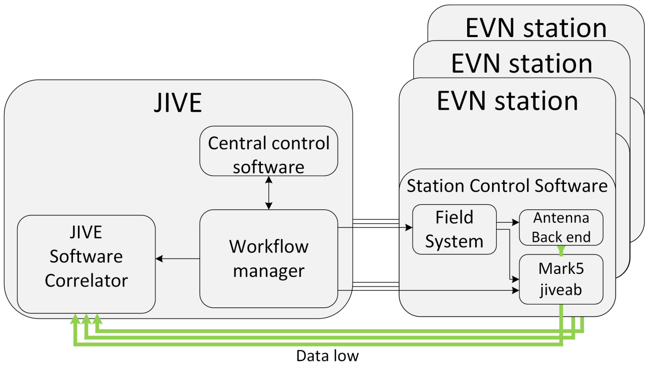

Fig. 2. The schema of communication routes and the data flows in e-VLBI session in EVN

Typically 10 to 16 antennas participated in the e-VLBI sessions. Each antenna should be equipped with the station control software including the NASA Field System (FS) (Himwich et al. (2003)) unit and Mark5 (Whitney (2003)) or equivalent registration unit. Central control software of session produces the schedule for each station and defines parameters for the software correlator. The Workflow manager communicates with each station, prepares the data flow from the stations Mark5 unit to the correlator. An example of correlation results – the calculation of correlation function, the spectra of reference antenna and each of the participated telescopes is presented in the Figure 4 from the section 3.1.

2. PREPARATION OF THE RADIOTELESCOPE RT-32 FOR E-VLBI

Recently, Ventspils International Radioastronomy Centre (VIRAC) operates only one of the two owned radiotelescopes located in Irbene - the RT-32 (fully steerable parabolic antenna with the mirror diameter D=32 m). The RT-32 mainly is used for a fundamental and an applied research in the field of radio astronomy such as studies of the solar microwave emission, the ionosphere research, the space debris and near Earth objects studies (Bezrukov (2013); Dugin et al. (2013); Nechaeva et al. (2013)). Other one, the RT-16 may not be used for VLBI due to it's poor technical condition.

At this moment the RT-32 telescope is fitted with the receiving systems for the frequency range 327 MHz to 12 GHz. A set of recording equipment has been assembled, which allows recording the signal in two channels with a bandwidth up to 1 GHz per channel. The recording system provides a high stability of the time frame which is prerequisite for the VLBI observations. In 2012, the radiotelescope RT-32 took part in 15 successful international VLBI sessions.

On the RT-32 it is possible to use the following receiving systems:

- 327 MHz (92 cm, P band) primary focus;
- 1.6 GHz (18 cm, L band) secondary focus;
- 5 GHz (6 cm, C band) secondary focus;
- 6.9 9.3 GHz (3.7 - 4.2 cm) secondary focus;
- 12 GHz (2.3 cm, X band) secondary focus.

As can be seen from the above list, all receivers are installed in the secondary focus except the 327Hhz receiver. As a rule, the preparation for the observations in these bands requires the mounting of a suitable feed after removing the previously installed as well as connection and calibration of the high-frequency unit (RF-unit). For example, usually to change the operating frequency is time-consuming process (from several hours to one day).

The receiving units at 12 GHz and 6.9 9.3 GHz dedicate for single dish observations, at 327 MHz, 1.6 GHz and 5 GHz are more versatile and designed for the use in VLBI observations. The frequency bands of 327 MHz and 1.6 GHz are employed extensively in the VLBI experiments intended for studying the ionosphere and the solar activity in the collaboration with Radiophysical Research Institute (RRI) in Niznij-Novogorod, Russia (Nechaeva et al. (2013)). The receiving system for the 5 GHz band is mainly engaged for the location of the space debris and in the EVN experiments, it is also used in the e-VLBI observations (Bezrukovs et al. (2012)).

The connection scheme of EVN e-VLBI observation process at the RT-32 including the receiving and the recording systems is shown in Figure 3.

The e-VLBI observations were conducted using the receiver with 5 GHz bandwidth, which was produced in the early 1990s for Medicina[2](a radio astronomy observatory in Italy), where it was installed and used until 2008. After dismantling, the receiving system was handed over to the VIRAC. At present, the receiver is placed in the secondary focal room of the radiotelescope RT-32 at Irbene. The receiver is used at ambient temperature, without any cryogenics system installed. This although significantly reduces the sensitivity of the system, and it still allows participation in the VLBI tests. The receiver has the following parameters: the frequency range: 4700 – 5500 MHz, the intermediate frequency: 100 – 450 MHz, the noise temperature: 100 K. The received signal from the feed-horn through the wave-guide arrives at the orthomode transducer (OMT) which performs how to split the wave in the right- and left-polarized components. A signal generator R&S SMP 04 is used as the local oscillator.

[2]Medicina radioobservatory, Instituto di Radioastronomia, INAF, http://www.ira.inaf.it/Radiotelescopes.html

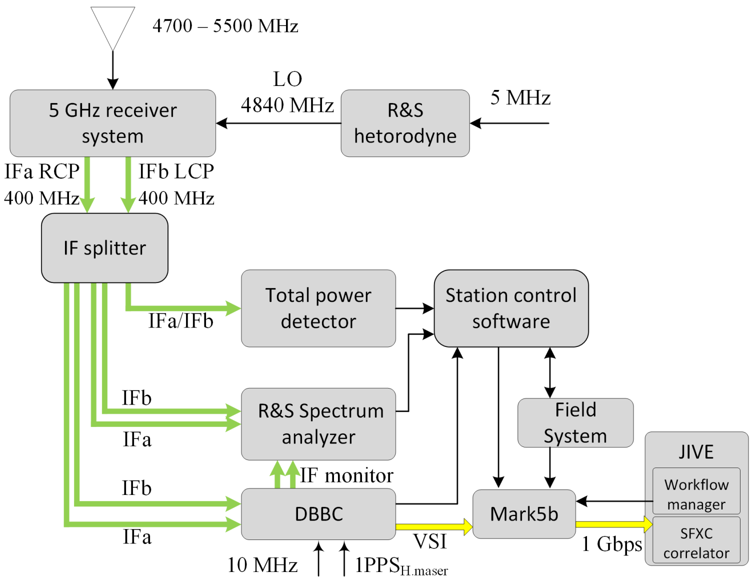

Fig. 3. Connection scheme of receiving and recording equipment for e-VLBI experiments at the RT - 32

The data acquisition system consists of two units: DBBC complemented with Mk5b (Mark5b). The DBBC – the Digital Base Band Converter, developed at the Institute of Radioastronomy, Noto as a generic, modular radio astronomy data acquisition architecture to be used inside the European VLBI community. DBBC2, which used in the RT-32, can simultaneously handle up to four IF channels. The input signal has a bandwidth of 512 MHz and a sample rate of 1024 MHz. The digitized signal is fed to Mk5b by VSI-H interface. Since the Mk5b model installed at the observatory is equipped with only one VSI-H cable, and it is possible to record only two inputs – IFa and IFb. Each IF is processed by CORE2 board and is splitted in four channels with the maximum bandwidth up to 32 MHz (16 MHz upper side band and 16 MHz lower side band) (Tuccari et al. (2010)).

The system Mk5b is used for recording the sampled data flow. The system is developed as the first Gbps VLBI data system based on the magnetic-disk technology. Incorporating primarily low-cost PC-based components, the Mk5b system supports the data rates up to 1024 Mbps, recording to an array of an inexpensive removable IDE/ATA disks. For synchronization, Mk5b uses 1PPS and 32MHz signals obtained through VSI-H interface from the DBBC. In the existing configuration the maximum data rate is 1 Gbps (Whitney (2003)).

Mk5b via a dedicated 1Gbit optical line connected to Ventspils city and next to the NORDUnet network which in turn makes it possible to link Mk5b and JIVE SFXC correlator (Kettenis et al. (2009)).

The control of Mk5b recording system and the telescope movements are carried out by software Field System.

Overall management and control of all units is done by station control software which receives the information of the registered spectra and the spectra total power in RCP and LCP IFs, the position of the telescope and the digitalized data flow.

The VLBI observations require a precise synchronization of the received and the sampled data and a linking to the exact timestamps. As the frequency and time standard for the RT-32 an active hydrogen maser Quartz CH1-75A is used which generates a reference frequency of 5 MHz and a 1PPS signal, while Symmetricom XLI Time and Frequency system is employed for setting and checking the time scale. This system generates one-second pulses based on the signals from GPS satellites. In addition, it has an NTP-server providing accurate time transfer to all devices of the telescope via a Local Area Network. To control the synchronization of the acquisition system, a four-channel oscilloscope R&S RTO 1014 is applied, which displays the PPS signals from GPS, DBBC, Mk5b, 10 MHz from DBBC and 5 MHz from hydrogen frequency and time standard. In the case when one of the devices loses synchronization, this will be easily detected on the oscilloscopes display (Bezrukovs et al. (2012)).

3. E-VLBI OBSERVATIONS

During 2012 the RT-32 participated in the several EVN Network Monitoring Experiments (NME) using receivers of the C and L band. The first successful detection of the fringes in the EVN was done in April 2012 using receiver of the C-band (experiment FR012), later the fringes was obtained in the spring and autumn in EVN NME experiments(also in the C-band). The observations in the L-band was unsuccessful due to the low sensitivity of the receiver.

The connection scheme of the receiving and the recording equipment developed and tuned during the NME are presented above and have been tested in e-VLBI experiments in collaboration with EVN observatories. The first tests have been carried out in cooperation with Torun observatory and Poznan Supercomputing and Networking Center (PSNC). In these tests the optical fibre throughput was estimated, also software and telescopes backends was tuned successfully. Some time later after the first VLBI fringe, the participation with the subsequent experiment within EVN e-VLBI session yielded its first successful results.

3.1. THE FIRST E-VLBI FRINGES

On 19 of March 2013 the observation session was typical C-band e-VLBI session. In the experiment named EG069C ten EVN observatories (Jodrell Bank, Westerbork, Effelsberg, Onsala, Medicina, Torun, Yebes, Hartebeesthoek, Not) participated including the radiotelescope RT-32 at Irbene. Good practise in EVN is to carry out the calibration session before the scientific observation with the aim of harmonizing all the observatories, checking the network throughput and the software correlator performance. Irbene got the first eVLBI fringes in the mentioned calibration session.

Observation was performed at a frequency band: 4926.49 - 5054.49 MHz, with the total bandwidth 128 MHz for each LCP and RCP polarization. The registered bandwidth was splitted in the 16 channels for 16 MHz band per channel. Although the capacity of the network allows to transfer data with the maximum speed to 1 Gbps, the limit of the Mk5b restricts the speed rate to 700 Mbps. Therefore, in this experiment Irbene used a one-bit quantization and at the result the data rate was 512 Mbps. As the observation target was used standard VLBI calibration sources 3C454.3, 0234+285, 0528+134. As the reference antenna was used Effelsberg radiotelescope for the fringe detection.

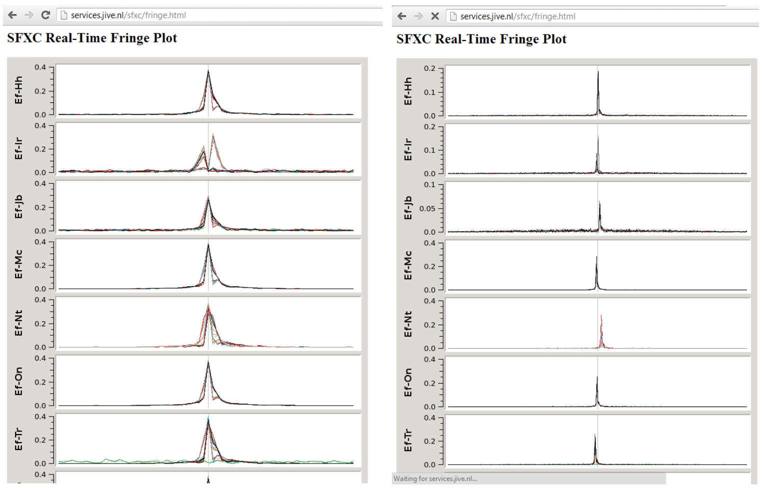

Fig. 4. Two snapshots of the real-time fringe plots calculated with SFXC correlator in JIVE during EG069C experiment. The second snapshot (from the top) is displayed the results of the correlation functions of the baseline Effelsberg – Irbene (Ef – Ir). (services.jive.nl/sfxc/fringe.html)

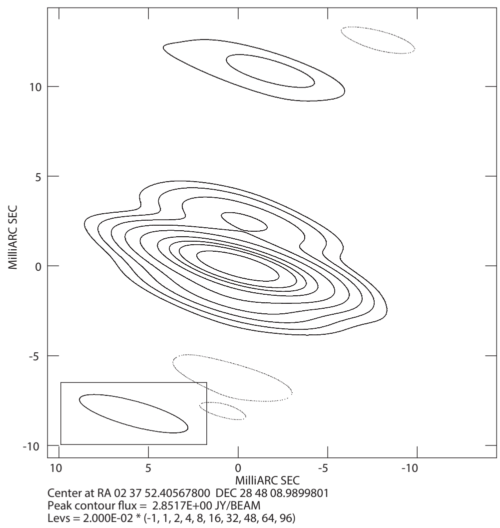

Fig. 5. The total intensity map of source 0234+285 at 4.990 GHz, the experiment EG069C. The lines of black contour represent the intensity of the levels with the peak flux 2.8 Jy/beam. The ellipse in the left bottom corner is the synthesized beam of the EVN array.

In this session the baseline Irbene–Effelsberg yielded it's first e-VLBI fringes, the first successful e-VLBI result for VIRAC. An example of two real-time fringes are presented in the Figure 4. The first VLBI map included obtained results from Irbene was constructed after the experiment. The total intensity map of the source 0234+285 at 4.99 GHz is shown in Figure 5.

3.2. IRBENE AND TORUN EXPERIMENTS

Recent implementations of e-VLBI technology allow to split the large amount of radioastronomical data (1Gbps from each station) from antennas in several data flow and correlate each data flow in the seperate correlation centre in the distributed correlation mode. It is worth to notice that now the data processing can be performed faster and more efficient. Also the data processing can be performed not only in JIVE, but also at smaller institutions as VIRAC which is interested in the results of particular e-VLBI sessions.

Usually the data processing (correlation) is performed with the aid of devoted hardware (High Performance Computing cluster - HPC cluster) and a software correlator. Several software correlator types for e-VLBI purpose are known, two of these are used in the described e-VLBI tests with RT-32 involvement. The software correlator DiFX (Distributed FX, (Deller et al. (2007))) is deployed on PSNC (Poland), while installation of SFXC correlator exists on VIRAC HPC cluster (30 nodes, 120 cores). Both types of correlators have the e-VLBI data processing capabilities.

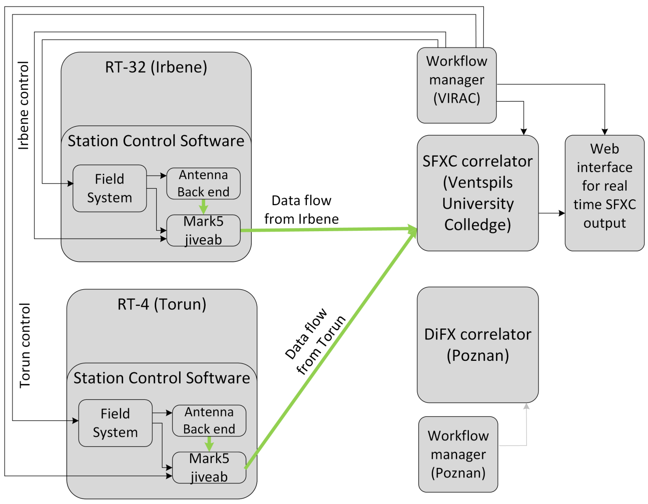

Fig. 6. e-VLBI experiment. Data flow from the Torun RT-4 and the Irbene RT-32 correlated in VIRAC SFXC correlator. Experiment managed by VIRAC operator

On 2013 an important collabrations between Irbene and Torun was made with the aim of improve the e-VLBI technology at both observatories. Several e-VLBI sessions were organized included two antennas - VIRAC's RT-32 and similar radio telescope in Torun (Poland) observatory (D = 32 m) and DiFX (deployed in PSNC) and SFXC (deployed in VIRAC) correlators. For e-VLBI tests the standard VLBI calibrators like 3C48 and 0433+295 were chosen. Thus, only two data streams were cross-correlated. The management of the data processing was mutually exclusively taken by both operators, DiFX(PSNC) and SFXC(VIRAC), as shown on schematic drawings of the control and the data flows in Figure 6 and Figure 7. The data transfers in real-time were tested at the variable configurations of the antennas and the correlators, as well as - at the variable amount of channels (2, 4, 8, 16) and a discretization(2MHz, 4MHz, 8MHz). In the tests the e-VLBI models as

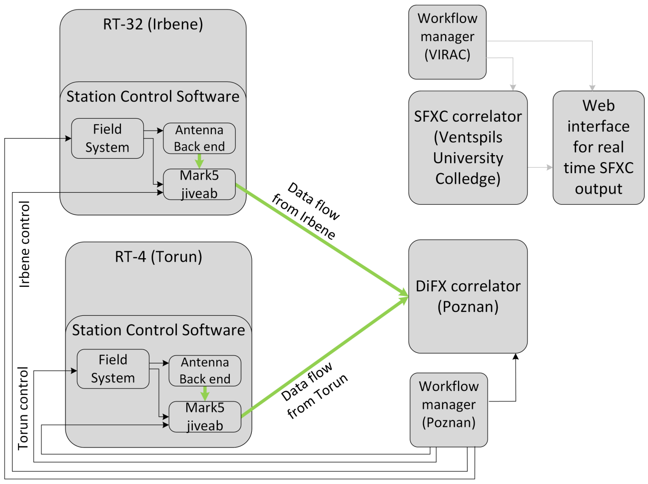

Fig. 7. e-VLBI experiment. Data flow from the Torun RT-4 and the Irbene RT-32 correlated in PSNC DiXF correlator. Experiment managed by PSNC operator

”Irbene and Torun antennas - SFXC”, ”Irbene and Torun antennas - DIFX” were implemented.

The results of these experiments demonstrate the possibility of correlation of two data flows from Irbene and Torun observatory using VIRAC SFXC correlator and PSNC DiFX correlator. Unfortunately, none of these experiments the fringes were not obtained - indicated the need for further the researches and the tests.

3.3. TRIGGERED OBSERVATIONS

Rapid data processing is the main benefit of the e-VLBI techniques. However, e-VLBI allows better organization of VLBI sessions as well. Therefore, its become to a powerful tool for studying transient events such as the supernova explosions and the gamma-ray bursts. If an interesting astronomical event occurring, it could be observed by the array with an extremely short notice. The information source of such an event may be an instrument of operations at different wavelengths to the array and therefore the array can provide complementary observations (Swinbank (2009)). VIRAC participated in the Novel Explorations Pushing Robust e-VLBI Services project (NEXPReS). One of the project goals is to develop triggering system for EVN e-VLBI observations. This system should react to the event, prepare new schedule and manage the stations and the correlator work (van Langevelde (2010); Szomoru (2010)).

The operation scheme of system is presented in Figure 8. After trigger event observed, new schedule is generated and uploaded to the station FS. The workflow manager terminates the FS current (background) schedule, runs the triggered schedule, starts the data flow from the Mark5 unit and initiates the correlation procedure. After finish of the triggered schedule the workflow manager returns to the background schedule, if its not ended[3].

[3]NEXPReS is an Integrated Infrastructure Initiative (I3), funded under the European Union Seventh Framework Programme (FP72007-2013) under grant agreement No. RI-261525. projects

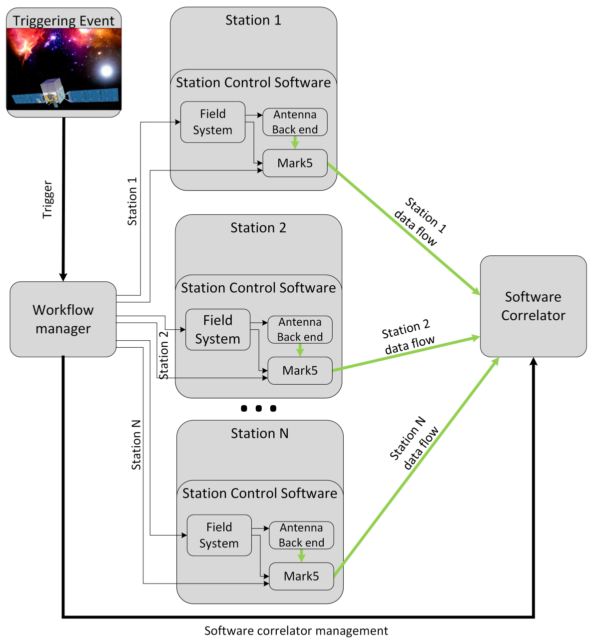

Fig. 8. Schematic of triggered e-VLBI observations

4. CONCLUSIONS AND FUTURE WORK

Currently the Irbene radiotelescope RT-32 is fitted with the receiving systems for the frequency range from 327 MHz to 12 GHz, the receiver of 5 GHz with VLBI data acquisition system were tuned and tested in the EVN NME test experiments where the first fringes were detected in April 2012. During 2012 the RT-32 demonstrated an ability to participate in the EVN sessions.

In this year the RT-32 have been prepared for the e-VLBI observations. Several experiments were conducted with Torun observatory, which helped to join the e-VLBI comunity with successfully implemented the e-VLBI components. In March 2013 the above mentioned experiments made it possible to successfully participate in the e-VLBI observations (managed by EVN) where the first Irbenes e-VLBI fringes were obtained.

Participation in the NeXPRESS project allowed to establish the SFXC correlator on VIRAC HPC facilities. In the future e-VLBI data correlation may move to the distributed correlation, therefore as one of correlation centres can be used VIRAC HPC cluster with installed software correlator of the SFXC type.

To date, despite the fact that the RT-32 carried out a number of successful tests of VLBI in EVN, for full participation in the scientific EVN observations - several technical improvements are needed. By end of 2013 should be installed cryogenic equipment for 5 GHz receiver that increases sensitivity of antenna. Soon work by the modernization of the drive and control system of RT-32 will begin with the aim to increase the pointing accuracy of the antenna. The renovating and

homepage http://www.nexpres.eu/

the adjusting of the surface of the antenna are planned over the next two years.

5. ACKNOWLEDGMENTS

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