Technical Status and Developments of the EVN

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We present an overview of the technical status and current developments of the European VLBI Network (EVN), including an introduction of its Technical and Operations Group, the TOG. The telescopes, observing frequencies, and the types of observations run are briefly presented. We also describe the EVN VLBI backends and recorders and the developments performed during the last two years whose main goal has been achieving 2 and 4 Gbps recording rates.

Keywords: VLBI, EVN

1 Introduction

The European VLBI Network (EVN) is a collaboration of the 14 major radioastronomical institutes in Europe (including the Joint Institute for VLBI, an ERIC since recently), Africa and Asia, whose main goal is performing astronomical high angular observations of cosmic sources. This is achieved using Very Long Baseline Interferometry (VLBI) among telescopes at the different observatories of the institute members. The EVN operates 21 telescopes and 2 correlators.

The EVN has a governing body formed by the Consortium Board of Directors (CBD), a Technical and Operations Group (TOG) and a Programme Committee (PC). The chairs of the two latter groups report to the CBD every 6 months.

2 The TOG

The TOG dates from 1983 (Porcas, 2010), although by that time it was called Technical Working Group (TWG). The meetings in those early years had a periodicity of one year until 1989. The name TWG was changed to TOG in 1998. Minutes from past meetings are public available since 1992
(http://www.oan.es/evn/togmins/togmins.html).

The TOG is in charge of the operations and technical developments of the network. It is composed by VLBI friends at the stations and personel at the correlators. The TOG meets periodically approximately every nine months rotating the location through the different observatories. The meetings are open and are also regularly attended by non-EVN members, like the FS main developer or staff from Haystack and NRAO. The meetings are organized to avoid happening within EVN sessions and, since 2014, every three times the TOG chair tries to match it with the EVN symposium and the EVN user's meeting, looking for a direct interaction between the technical personnel and the users. Since 2016, the TOG meets together with the Global Millimeter Array (GMVA) Technical Group every other meeting. In these cases the meetings last two days, devoting one day for the TOG and another for the GTG. The goal is to exploit synergies, looking for common developments and benefiting from the exchange of information between both communities.

The TOG resources are distributed among different EVN partners who host different servers. The main TOG web page is currently hosted at
http://www.oan.es/evn/tog.html and it acts as starting point to access all the resources. This page is also reachable from the main EVN web page:
http://www.evlbi.org.
The sources of information are the TOG wiki, hosted by MPIfR in Bonn:
https://deki.mpifr-bonn.mpg.de/Working_Groups/EVN_TOG.html
and Radionet3 wiki web page:
http://www.radionet-eu.org/radionet3wiki/doku.php?id=na:eratec:tog.
The first one contains information about disk status, disk purchases, spares, last and permanent action items and technical information, including scripts, procedures and descriptions to perform tasks at the stations. The second wiki is basically devoted to TOG meetings and it hosts the agenda, minutes, reports and talks from last meetings. JIVE web page and servers maintain all information regarding feed back from observations, observed and correlated experiments and about real time correlation. Schedules and logs are stored in the EVN FTP hosted by the Instituto Nazionale di Astrofisica (INAF) in Italy. The main communication channel is the mailing list hosted by Jodrell Bank and known as the EVNtech email list.

3 EVN telescopes and observing frequencies

As mentioned in the introduction, the EVN operates 21 different telescopes. Their characteritics are compiled in the EVN status table maintained by B. Campbell where the station code, diameter, available frequencies, SEFD for each observing frequency, backends and recorders can be found.

The EVN observes between 21 cm and 7 mm and some telescopes can even observe at 91 cm. There are eight main bands whose frequencies have been chosen to make them match with interesting spectral molecular or atomic lines. Table 1 lists the frequencies, bandwidths and lines in which they are centered. 91 cm band is the lowest frequency band and it is only available in 4 (5) telescopes. The 21 cm band is centered in the atomic H line, and the 18 cm one is centered in the OH maser line, 13 cm and 3.6 cm are also bands chosen because they are compatible with geodetic S/X observations. Other bands are 6 cm and 5 cm, the latter centered around the CH_3OH maser line. Finally the upper bands are 1.3 cm around the H_2O maser line and 0.7 cm around the SiO maser line. Available instantaneous bandwidths depend on the frequency ranges and vary between stations, being the largest 500 MHz. Many telescopes can tune their local oscillators and their observ-

Table 1
Frequency bands covered by the EVN. Band widths depend on individual stations

Band, cm	Bandwidth, MHz	Main interest
91	32	continuum emission
21	60 – 500	H maser
18	60 – 500	OH maser
13	300	S/X geodetic S band
6	500	Continuum emission
5	425, 500	6.6 GHz CH_3OH maser
3.6	500	S/X geodetic X band
1.3	100, 400, > 500	22 GHz H_2O maser
0.7	> 500	43 GHz SiO maser

able bands are larger than 500 MHz, for example several GHz for 22 and 43 GHz. The most used bands during EVN observation are 5, 6 cm, and 18-21 cm.

4 Backends

The EVN uses 6 different VLBI backends: VLBA, DBBC, DAS R1002, CDAS, KDAS and DVP.

Most of the EVN telescopes are equipped with DBBC2 backends built by HAT-Lab in collaboration with MPIfR. The DBBC2s (Tuccari et al. 2009) contain 4 IFs and 4 COREs and a Fila10G board which can generate VDIF data rates up to 8 Gbps. The standard mode can yield 16 channels up to 16 MHz each, being the bandwidth tunable up to 32 MHz per channel. However not all telescopes have fully equipped DBBC2s.

The KVAZAR russian telescopes use their own DAS R1002 backend (Nosov, 2011). CDAS R1002 has similar characteristics to the DBBC2: 4 IF inputs, 16 channels with a tunable bandwidth, a maximum recording rate of 2 Gbps and VSI-H (Mark5B) format.

The Korean KVN stations use their own system, the Korean Data Aquisition System (KDAS), see Oh et al. (2011) with 4 IF inputs, 16 channels and delivering VSI-H data at 2 Gbps.

Some Chinese stations use DBBC2s but also the Chinese Data Aquisition System (CDAS), see Zhang et al. (2012), with similar characteristics to the previous backends: 4 IFs with a maximum bandwidth of 500 MHz, 16 channels and two VSI-H outputs.

Robledo uses a data aquisition unit (DVP) built by JPL, with 2 IF inputs 500 MHz bandwidth and a maximum of 32 channels and capable of generating VDIF data (García-Miró, 2015) and Arecibo still uses a VLBA terminal.

5 Recorders

Recorders used are Mark5A, Mark5B, Mark5B+, Mark5C, Flexbuff and Mark6. Updated information on the recorders, except for Flexbuff and Mark6, and the firmware that they use is compiled in the following web page: http://mark5-info.jive.nl/.

Most of the stations record in Mark5B format, but the usage of VDIF format started in 2016 and currently 7 stations use it regularly: Ef, Hh, Mc, On, Ro, Sr and Ys.

All versions of Mark5 recorders use VSI-H as input, except the Mark5C, and all of them use diskpacks which can be shipped to the correlator. Diskpack capacity can be as high as 48 TB, and to manage such higher capacities the latest firmware should be used. The increase of size of the packs and its wide adoption for economic reasons, has created a quantization problem: stations usually send the recorded packs once they are full. This may be a problem for observations which require low space but need a fast correlation or when experiments on the same session need to be sent to different correlators.

The new recording systems, Flexbuff and Mark6, avoid disk shipping and therefore do not suffer the quantization problem but they rely on data transport through Internet where high speed lines are required. The Flexbuff is a COTS system using a raid of disks and running a software developed at JIVE, jive5ab. A Mark6 with 4 diskpacks can act as a Flexbuff thanks to jive5ab software and from the point of view of the operations does not differ from the former.

6 Frequency modes

Standard observations at the EVN consist in observing two bands 128 MHz wide each at right and left circular polarization, which corresponds to a recording rate of 1024 Mbps. This rate is limited by a DBBC2 equipped with 2 COREs and a Mark5B recorder if the Mark5B format is used. Higher rates require DDBC2s equipped with 4 COREs in DDC mode and at least a Mark5B+ recorder. Since EVN session 2015-3 the EVN offers two bands 256 MHz wide with a recording rate of 2 Gbps at all stations except three (Tr, Ar and Wb) and the KVN.

Two types of frequency observing modes are available: Digital Down Conversion (DDC) and Polyphase Filter Bank (PFB). The DDC mode is supported by all EVN backends, and consists in splitting the observing band in 16 channels, usually 8 channels per polarization. All channels must have the same bandwidth but they can be selected at different frequencies along the IF band. The bandwidth can be selected in powers of two: 1, 2, 4, 8, 16 and in some cases 32 MHz. Narrower bands are possible but they are not usually used. The maximum recording rate for this mode is 2 Gbps which corresponds to two bands 256 MHz bandwidth.

The PFB mode does not allow frequency tunning: all channels have a bandwidth of 32 MHz and are distributed contiguously. The maximum number of channels is 16 per polarization, but some of the channels can be dropped using a mask which selects those required. The maximum recording rate for PFB is 4 Gbps. Not all current VLBI backends support PFB mode although all of them could mimic the behaviour using DDC at recording rates of 2 Gbps. The DBBC2 can manage both modes, but it requires loading the appropiate firmware in each case.

7 EVN observations

The EVN groups observations along the year in 3 o called sessions. Several weeks prior to each session there is a call for proposals evaluated by the program committee (PC). Proposals best rated are scheduled and observed. Each session is divided in blocks according to the observing frequency. Sessions usually happen in February/March, May/June and October/November. The scheduler keeps contact with the Global Millemeter Array (GMVA) scheduler and the IVS scheduler to avoid observational conflicts since some EVN telescopes also belong to the GMVA and IVS networks. The number of observations programmed depends on the available disk space at the stations and correlator. Currently, with a recording rate of 1 Gbps, the typical usage per station and session is approximately 90 TB. Schedules are made by JIVE where a customized catalog and a patched version of SCHED is kept.

Apart from the standard science observations during sessions, the EVN performs other types of observations.

Network Monitoring Experiments (NME) are observations that precede a frequency block during an EVN session. Stations transfer slots of selected scans to the correlator where the data is correlated. The goal of these observations is to debug problems some hours before the science observations start, to be able to tackle them.

Fringe tests are other type of EVN observations and their purpose is to test a development and hence they are not restricted to EVN sessions; they can be scheduled at any time and usually are restricted to a subset of telescopes, those which are available and willing to implement the new features to test. Both types of observations are correlated in near real time, and the results displayed in a web page at JIVE: http://www.evlbi.org/tog/ftp_fringes/. There are some cases in which some Fringe Tests are diskless and the data is tranferred in real time to the correlator.

Out of session Observations (OoS) happen 6 days per year. They require a long term cadence and time specific requirements and they are usually associated to the Radioastron project.

e-VLBI observations are diskless, since the data are transferred to the correlator in real time where they get correlated. Each observation usually takes 30 hours and they are distributed along the year, in several periods. Usually the first six hours of the observation are reserved for tests. Target Of Opportunity (ToO) observations is another category of observations whose goal is to react to a transient event. They require a fast review and scheduling and if their rate is high enough they can override a running schedule. For the time being ToO observations can only happen during an e-VLBI period.

All observations automatically send the LOG to the EVN FTP server hosted in Bologna, Italy, and observers fill a feedback form after the observation has completed which may be useful during the correlation process. After the observations are over, stations upload antab files which contain amplitude calibration data as a function of time. The antab files are generated at each station from the "log" files. Previous to the EVN sessions telescopes should reserve time for an amplitude calibration observation that allows to determine the gain of the antenna and noise temperature of the diodes along a frequency band. This is achieved with ONOFF observations.

8 Technical developments

During the last two years, tests and developments have focused in achieving a recording rate of 2 Gbps for recorded and e-VLBI experiments and 4 Gbps for recorded experiments. To achieve this goal the EVN signed a contract with NVI Inc. in 2015 to provide new features at the FS which had to be completed in one year approximately. This agreement was composed of three steps which had to be covered by a FS release each time and that we explain below.

The first step consisted in providing support for 32 MHz per channel in DDC mode for the DBBC2. FS version 9.11.7 released in April 2015 and the DBBC firmware V105E_1 released by HAT-Lab in January 2015 covered this goal. This mode is available within the EVN and it was offered in the call for proposals since fall 2015 although not all stations support this rate.

The second step consisted in providing support for VDIF data and therefore for Fila10G, Mark5C, Flexbuff and Mark6 recorders. VDIF stands for VLBI Data Interface Format (see http://www.vlbi.org/vdif/) and provides a great flexibility in the encapsulation of the VLBI data. VDIF support was acomplished by Fila10G firmware version 3.3, FS version 9.11.8 and jive5ab versions above 2.6.0. Since October 2015 this format is supported and available within the EVN. The adoption has been gradual since then and by the end of 2016, 7 EVN stations (Ef, Hh, Mc, On, Ro, Sr and Ys) provide data in such format.

VDIF support is provided by jive5ab (recording) software which is a crucial tool in the EVN; the TOG agreed in 2014 to replace Dimino by jive5ab at all EVN stations. jivea5ab is a development mainly by H. Verkouter (JIVE) and it manages the recording of data. It works on Mark5A, Mark5B, Mark5B+, Mark5C, Mark6 and Flexbuff. It is supported in 32 and 64 bit OS Linux versions and works for several Debian versions: Etch, Lenny and Wheezy. jive5ab supports VDIF and Mark5B format. Together with jive5ab, some useful tools have been developed and released: m5copy allows to copy data between different recorders or between a recorder and a standard Linux host and viceversa. This method has gradually replaced tsunami to transfer data between the stations and the correlator due to its high reliabilty and the high speeds, up to 800 Mb/s, that it can attain. Other tools specially interesting for Mark6 and Flexbuffs are vbs_ls for listing and searching scans across different disks, a virtual file system, based on fuse that allows to gather the data from an experiment and a graphical version of m5copy. All these tools, developed in the last two years, greatly simplify the management of data at the stations and the correlator.

The third step consisted in providing support for the PFB mode. This is the mode that will be required for 4 Gbps operations since DDC is currently limited to 2 Gbps. FS version 9.11.16 to 9.11.18, released between October and November 2016, provide such support. Many fringe test experiments have been performed since January 2016 to test the developments and debug issues with the PFB DBBC firmware. At the time of this article the current FS version supports radiometry and the DBBC firmware seems to be stable and work without problems. However further tests will be conducted in the next months.

The adoption of a recording rate of 4 Gbps and the PFB mode will require a common local oscillator setting across the telescopes in the EVN. Currently stations can use different local oscillator frequencies to observe the same sky frequency since the differences are absorbed in the different DDC mode frequency channels. The usage of PFB mode disallows this solution and the local oscillators should match exactly or differ 500 MHz depending on the Nyquist zone they use. If the band were smaller than 500 MHz, they may differ in multiples of 32 MHz. We foresee that this mode will be specially important at 22 GHz and 43 GHz. Its application at C and X band will depend on the RFI at the different stations and in a global agreement of the band to be observed.

Another technical development acomplished by the TOG has been the adoption of 2 Gbps e-VLBI. This mode has been implemented after extensive tests performed during the last months. The usage of Mark5Bs imposed a limitation of 1 Gbps in the transfer of data in real time. The correlator connected to the station's Mark5B or Mark5C units and managed (started and stopped) the data flow using jivea5b. Increasing the data rate to 2 Gbps required that the DBBC2 sent the data directly to the correlator. The DBBC2 generates data in VDIF format that can be sent in a single thread with different frames, one per frequency band, or in different threads, one per frequency. In this latter case the correlation can be distributed across different CPUs. Both cases were tested; the single thread multi-frame works with a payload of 8000 bytes per frame and the multi-thread single-frame one with 2000 bytes. The former matches the requirements of the correlator, while the second one, although it also matches the capability of the correlator it imposes a load in its CPU: smaller frames require more processing. The data flow control from the correlator has been achieved by a proxy at the stations, a server program that listens to the FS and to a second client (from the correlator) and which forwards commands to the DBBC2 and receives answers which are sent back to the caller. This allows the correlator to configure the Fila10G and remotely start and stop the data flow. The proxy is installed on a host in the public local area network to prevent malicious access to the FS which controls the radio-telescope.

Following this development the EVN announced in the last call for proposals, in May 2016, the possiblity to perform e-VLBI observations at a rate of 2 Gbps with at least 6 stations. Once the 4 Gbps recording rate mode is fully tested, this mode will be announced at the EVN and it should also be available for e-VLBI observations provided the stations have 10 Gb/s connection lines to Internet.

One of the most pursued developments of the EVN is the implementation of continuous calibration. Single shot calibration has been the tradicional method and it consists in switching on and off a noise diode with a known calibration temperature before each scan. This procedure requires time, between 10 to 20 seconds, and since telescopes have different slewing rates it is performed at different times within a schedule at each station. A better aproach consists in injecting permanently a fast, 80 Hz for example, switched signal with a low level noise diode that does not increase the system temperature more than 5%. This signal is detected synchronously by the backends and can be used to measure the system temperature periodically through the scan. The advantages are basically two: the system temperature is measured almost continuously and no time is lost at the beginning of each scan. Currently four stations (Ef, On, Ro and Ys) use this system. In the next months more stations will implement such system and it should be widely used at the EVN stations in the near future.

The last year has seen much activity to include Irbene and Kunming stations in the EVN network. Both stations took part in the last 2016 EVN session with successful results in the NME experiments. Irbene can observe at L, C, M and X bands, record at 2 Gbps rates and transfer data at that same speed for e-VLBI observations. They took part in all observations. Kunming has recently installed a C and M band receiver and can also observe at X band.

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