Overview of new capabilities (AI: IRB-09)

P. de Vicente (TOG chair)
26/4/2017

This action item, complex in its drafting and in its content, is rather ambitious and hence, the notes and ideas expressed below should be considered just a starting point.

The content was discussed among several TOG members in a telecon on April 11, 2017, almost one month before the CBD meeting, as requested. We mainly discussed about the potential developments in the mid term future. The timeline and costs of each item are difficult to estimate and we have not been able to make a realistic estimation of some of them. At the end I have prepared a table with a summary of elements to be considered.

What the users request

Last EVN users' meeting in Saint Petersburg in 2016 discussed about the future EVN developments and sorted the priorities as listed below:

1. Improved frequency agility
2. e-VLBI with more telescopes
3. Increased bandwidth
4. Extended observed time
5. Improved astrometry
6. Improved uv coverage
7. Improved resolution

According to the 3 most rated options the EVN should focus in being able to switch fast between different observing frequencies, increasing the number of telescopes that can do e-VLBI and increase its sensitivity by increasing the bandwidth. A larger number of telescopes also improves the UV coverage and if they are sufficiently far apart this increases the spatial resolution.

The future mid/long term developments of the EVN could be based on these priorities and provide further functionality to the network. The list that we provide below is a rough approximation to the goals the EVN could/should pursue.

Frequency agility can be achieved by installing a single broad band receiver which also provides an additional more ambitious feature: simultaneous observing frequencies. This should be the primary EVN technical goal and it is already covered in **Radionet BRAND** project lead by W. Alef for frequencies below 14 GHz. Additionally we also propose that telescopes whose efficiency and location is good enough should also consider the installation of a 22/43 GHz receiver that allows simultaneous observations. Again this was a project presented to Radionet by F. Colomer that was dismissed in competition with the previous one.

Below we will discuss in more detail these goals.

BRAND: wide band 2-14 GHz receiver

BRAND project has two goals to be accomplished within the next 4 years: installing a prototype broad band receiver at Effelsberg's 100 m primary focus and a feasibility study for a receiver in the secondary focus. Such wide band receiver would open a new frequency spectral band for the EVN between 8 and 14 GHz. Regarding the project I split below some technical developments that will be addressed during the project's life and that EVN stations may start evaluating locally and even implement them before Radionet is over:

- Development of new wide broad band feeds. Several designs are been considered. The most probable one is the QFRH by JPL which is already in use at VGOS telescopes. Other QFRH similar designs are being tested in Europe. Its cost is around 16 k€.
- Superconductor filters to reject RFI that saturate the low noise amplifiers. Some developments are on the way both in Europe and US. The cost is difficult to quantify since the development should match the RFI conditions at each location. Approximate cost: 6 k€.
- Wide band low noise cryogenic amplifiers. There are already some units from different EVN institutes. For example Yebes has already models between 1.4 and 18 GHz with very good noise temperature and gain. Approximate cost:
- Study of the RFI in the environment of the antennas. Equipment at Yebes is already available but it is not realistic travelling to all EVN stations for a measurement campaign. A workshop is being organized in June 2017 to educate staff at the stations so that they perform the observations themselves.
- Transmission of wide band IFs from the receiver to the backends room. The IFs should no longer be transmitted via copper cables but through optical systems. Optical fibers usually carry 8, 12 or 16 channels that can be used for different signals. Cost per channel, mostly for the transmitter and the receiver: 20 k€
- Tunable low phase noise Local Oscillators remotely operated to guarantee that higher bandwidths can be achieved at all telescopes and the local oscillator frequency is common at all stations. Cost: 12 k€

- Study of the impact of the usage of linear polarization at the correlator and development of required software. This is very difficult to estimate but is listed here as an item not currently solved and which will require some human resources. Cost: ?
- DBBC3 equipped with 2 IFs 0-4 and 4-16 GHz inputs. This setup only allows for a single frequency in two polarizations. Simultaneous observing frequencies would require a couple of modules, one per polarization per frequency. Cost: 100 k€ for a 4 IF module system with 4 cores that would allow two observing frequencies and two polarizations each.

About a 22/43 GHz receiver

22 and 43 GHz simultaneous observations should be considered at those EVN telescopes whose efficiency is good enough and whose locations allow to have acceptable opacities at both frequencies.

A compact design has already been proposed for mounting at the secondary focus, see Han et al. at the EVN users meeting. A less compact implementation is already available at the KVN antennas and at Yebes 40m radio-telescope. 22/43 GHz is an important frequency range that should be covered by the EVN. It is the frontier between the SKA and ALMA and the VLA covers it with 43 GHz receivers in most of their antennas. Simultaneous 22 and 43 GHz observations are an important strategy for observing at 43 GHz and 86 GHz with VLBI since phase corrections at the lower frequencies can be applied to higher frequencies. This scenario and strategy, presented by M Rioja in the ERATEC meeting in Arcetri (2015) led to an interesting discussion among the attendants to the “Multi-frequency mm-wave radio telescopes & Other software controlled operations” meeting. This strategy is already being used at the KVN and in the recently KaVa network. The EVN should also lead this initiative if the resources are available.

A science case summary and a technical proposal is mentioned in the document written by M. Rioja and R. Dodson that summarizes ERATec meeting in Florence. This document not only mentions 22/43 simultaneous observations, it also includes 86 GHz and 135 GHz as observing frequency ranges. This document has been included in the documentation for the CBD meeting.

The cost and timeline for such receiver is very rough. It will require low noise amplifiers at both frequencies, which already exist within the EVN, a dichroic mirror and tunable local oscillators. The backend would be the same as for the BRAND project.

A starting point for working at these frequencies should be to increase the frequency of NME observations even if there is no pressure from the user community or if the 43/22 GHz frequency is not requested. That would help stations and the correlator to gain experience in these observations and attract potential observers.

Backends: data acquisition units

Currently the only available backend that will accept bandwidths up to 4 GHz is the DBBC3. The DBBC3 is not a commercial off the shelf product and will require an extensive debugging that will last long. Our experience with the DBBC2 shows us that after several years since the first unit was released there are still issues that need to be corrected and fixed which are slowing the implementation of new features at the FS and the correlator. Furthermore, new firmware may come available once the DBBC3 is at the stations to provide additional features that may be needed in the future.

The DBBC3 will require backwards compatibility with the DBBC2. We propose using it in a progressive way at some stations within the EVN. Apparently 3 types of modes will be available: one GHz single channel per IF, DDC mode and PFB mode. The first mode will be the first available one and this will have an important impact on the correlator which prefers channelized modes (DDC and PFB) since it allows to distribute the correlation into different units. Investigation about this mode will be required.

The timeline for a stable DBBC3 is unknown but we believe that in 4 years time the firmware and hardware should be ready and available.

Other backends also being developed like BRAS (from Russia) and CDAS2 (from China). These backends have been thought as VGOS backends which support several bands 1 GHz wide and VDIF format. However it is not clear these backends will have channelization, like the PFB and DDC mode. Geodetic observations may prefer single channels to have the multi band delay be equal to the single band delay, but for astronomy this is not required and channelization is an advantage at the correlator.

The compatibility between the different backends is an issue to be addressed in future meetings like the IVTW and it sould be taken very seriously.

Recording systems

Recording systems in the future should aim for a rate of 32 Gb/s. They should be based on disk servers as the current “Flexbuff” with higher capacity. The usage of

Solid State Devices (SSDs) instead of Hard Disk Devices should also be considered because of their higher speed. In the near future costs will be similar for both types of technologies. The disk space will require a big amount of investment because it is always a limiting factor in the observing time.

2 Gbps operations should require 200 to 300 Tb per station and session. 4 Gbps will require doubling this number, 600 TB, and higher rates will increase the required space linearly. Therefor in the short/mid term future stations should be able to store 1 PB of data. The data will be transferred between the data acquisition data and the recorders using 4 10 Gb/s optical links. If more than one recorder is available at the telescopes the stations should be equipped with 10 Gb/s switches that allow flexibility in the connections.

The costs are difficult to estimate. Optical fiber switches with several ports are around 12 k€, current cost for disk storage is roughly 30 €/ TB.

e-VLBI and high speed connections

Both, recorded observations and VLBI, will require high speed connections at all stations. We recommend a bandwidth of 10 Gbps per station and one or two 100 Gbps links at the correlators. Links of 100 Gbps are already available and will become common in future. Bonn correlator should get a better connectivity in the near future. The cost of the connections depends on each station or correlator and difficult to estimate. Usage of dark fibers may be a good option if available since it is less expensive and allows to grow in the future.

Increasing the number of antennas capable of doing eVLBI should be a priority. Despite the efforts no fringes with eMerlin have been achieved yet. Another priority is the connectivity of the Quasar antennas. All antennas should be capable of transmitting at 4 Gbps within 4 years from now.

The capability to do eVLBI with 16 stations at 4 Gb/s should be feasible with 4 Uniboards at the correlator.

An estimate of the cost is uncertain.

More antennas to come

Jumping JIVE has several work packages about integrating new elements, VLBI in Africa and Geodetic Capabilities. Below I just mention the possibilities of growth in the next years.

New antennas in the horizon are 2 old communication antennas in the UK to be reconverted for C band observations, the 40m in Thailand and in the UAE (United Arab Emirates). Some new Chinese telescopes will also come up like FAST or a new 110 m in Quitai, Urumqi.

Another potential growth may come from Africa from reconverted old communication antennas.

Finally integrating new VGOS telescopes in Europe at Germany, Norway, Azores, Sweden, Finland and South Africa is also a possibility that should/could be considered.

Software development

New scheduling tools to address higher bandwidths, new backends and simultaneous observations should be developed. This is already addressed in one Jumping JIVE's work packages.

Developments for operating the backends and the observations, at the FS, will be required. The same applies for the backends control. This is an issue that should examined carefully since a plan that allows an easy maintenance, openness and potential growth is necessary. The implementation of new backends should be done in a modular way and should allow, if possible, different programming languages.

Software developments is mostly dependent on human resources and difficult to estimate. It should be coordinated with the VLBI geodetic community and with the GMVA.

<u>Table summarizing items for future technical developments</u>

Item	**Timeline (years)**	**Cost/unit**	**Block**
Wide band feeds	4	16 k€	Receivers
Superconductor filters	3	6 k€	Receivers
Tunable LOs	now	12 k€	Receivers
Low noise amplifiers	now	?	Receivers
IF OF	now	20 k€ /channel	Receivers

transmission			
BRAND receiver	4	300 k€	Receivers
22/43 GHz Rx	4	300 k€	Receivers
DBBC3	1	100 k€ / 4 channels	Backends
Recorders	now	?	Backends
Disks	now		Backends
10 Gbps lines	now	?	Connectivity
100 Gbps lines	now	?	Connectivity
Uniboards	now	?	Correlator
FS		?	Software
Scheduling			Software
Correlator			Software

Executive Summary

Potential developments and costs per station within the next 4 years:

- BRAND (broad band 2-15 GHz) receiver. Cost ~ 350 k€
- BRAND (broad band 2-15 GHz) receiver + 4 Gb/s recording + storage. Cost: 370 k€
- BRAND (broad band 2-15 GHz) receiver + 32 Gb/s recording + storage. Cost: 500 k€
- 22/43 GHz simultaneous receiver. Cost: 350 k€
- 22/43 GHz simultaneous receiver + 4 Gb/s recording + storage. Cost: 370 k€
- 22/43 GHz simultaneous receiver + 32 Gb/s recording + storage. Cost: 500 k€
- 10 Gb/s connections to the antennas. Cost: unknown.
- 100 Gb/s connection to correlator. Cost: unknown.