Progress with e-VLBI in the EVN and correlators at JIVE

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Abstract

The European VLBI Network has been offering real-time capabilities for a couple of years with a primary objective to allow observations of transients on the time scales at which they occur. The technical, operational and scientific aspects of this have been recognized to be relevant for the development of the SKA. As a next step, it is the aim to include an e-VLBI aspect to all user experiments, resulting in a more sensitive, flexible and robust network. Combined with new correlators, currently under construction, this will result in an astronomical facility complementary with other SKA-pathfinder radio observatories.

1. e-VLBI

VLBI is undergoing a silent revolution by providing real-time results, thereby enabling new science, boosting the reliability and potentially enhancing the sensitivity. This provides a natural growth path for high-resolution radio astronomy. And at the same time radio astronomers around the world are developing the Square Kilometre Array, which will presumably take radio astronomy into a whole different sensitivity domain. Certainly during the construction, but probably also during operations of the first two (lower frequency) SKA phases, a continuing scientific need will exists for high resolution VLBI capabilities. The fantastic progress in the European VLBI Network, catalysed by the EXPReS[1] project, has demonstrated that e-VLBI can be the way to provide this scientific instrumentation in the next decades.

In the last few years e-VLBI has evolved from an experimental technique, connecting a small number of telescopes at modest bandwidth into an operational astronomical service with competitive sensitivity and imaging capabilities. The project has been supported by the EC through the FP6 Integrating activity EXPReS, which has stimulated a large-scale collaboration between EVN technical staff and European Research Network providers. The initial argument for developing e-VLBI has been the desire to use VLBI on transient phenomena, being able to access the data on variable sources on the timescale that they vary. Indeed, opening the parameter space accessible to VLBI has turned up some very interesting results and various new science themes have been presented. However, the project has done more than enabling new science. It has also clearly demonstrated that e-VLBI is not a technique limited to do rapid response science. Because of its real-time nature it is also much more robust against failure, which can be noticed immediately and addressed instantaneously. With dedicated connections this has proven to be true, even though the high-speed links potentially add an extra layer of complexity. The various demonstrations have also taken away the scepticism whether e-VLBI could ever work for intercontinental baselines, showing fringes between telescopes on different continents simultaneously and routinely.

One way in which e-VLBI is less flexible than recorded VLBI is that its current operations do not allow re-correlations, which are for example needed to accommodate large numbers of telescopes or spectral line experiments that need mixed bandwidths. It is noted that in principle all of these are limitations of the current correlator, but even so it will be useful to introduce buffering of the VLBI data in various stages in order to combine the best aspects of recorded and real-time operations. The next step envisioned in the development of the VLBI of the future is to implement an e-VLBI component for every VLBI experiment that is carried out. By implementing transparent buffering mechanisms at telescope and correlator end, one can address all the current and future bottlenecks in e-VLBI. We envision an operational model in which all data that can be transported in real-time are correlated on the fly. Ideally such an e-VLBI experiment is completed directly after the observation, but there can be various logistic, technical and even scientific reasons, to access the data that was buffered and process the experiment a second time, possibly based on the evaluation of the real-time output. This way one could overcome limited connectivity to an essential station, or failures in streaming or correlation. Also reprocessing with different correlation parameters or new astronomical information on, for example source position, would be possible. Before any reprocessing is scheduled, one would have the possibility to assess the scientific need, based on the preliminary, real-time results. Such a scheme would also end

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almost all transportation of physical recordings, as buffering capacity on both ends could accommodate all scenarios. Such a scheme would also be more efficient in total disk capacity than the current model in which the recoding pool is fragmented to accommodate complex logistics. Implementation requires high-speed parallel recording hardware (many GB/s), as well as software systems that hide the bookkeeping from the VLBI components and their operators. A project to develop the above operations scheme has been funded by the EC under the name NEXPReS (Novel Explorations Pushing Robust e-VLBI Services)

2. Correlator development

The current EVN Mk4 correlator at JIVE that is at the heart of the EVN operations is capable of processing 16 stations at 1024 Mbps. Even though its capacities are still being enhanced, it is already necessary to invoke multiple pass correlation for a considerable fraction of experiments. This is required for large global experiments that use more than 16 stations at one time, or for high spectral resolution; notably this occurs when continuum sensitivity is required at the same time, for example in phase referencing. Similarly, higher than 1024 Mbps data rates can in principle be supported by multiple pass correlation, however, it is obviously not possible to accommodate high data-rates for e-VLBI in this way, as long as the data is not buffered at the correlator.

Various VLBI arrays around the world are adopting software correlators that can perform VLBI processing on commodity computer clusters. This approach is superior in flexibility and accuracy over hardware implementations and on moderately sized clusters these implementations perform similarly as the current hardware-based machines. At JIVE an independent software correlators has been developed in the context of the SCARIe/FABRIC programme and it is now operational at JIVE for specific VLBI projects.

For the longer-term future a large new EVN data processor is required. Looking at the above specifications and the EVN (and global) ambitions to have more stations, one can anticipate the need to process 32 stations (a factor 4 in baselines compared to the current), 16 Gbps per second (a factor 16) and maybe a 4 to 8 times better spectral resolution than the current EVN data processor. Overall the aim for 2015 must be to develop a correlator that is at least a hundred times more powerful than the current data processor. This calls for a machine of that needs to perform in a similar regime as the correlators for SKA precursors (MeerKAT, ASKAP), and some of the other pathfinders (e-MERLIN, EVLA, APERTIF). Taking future energy constraints into consideration, JIVE is actively pursuing for correlation on FPGA based architectures; a similar conclusion as was reached by other SKA pathfinder projects.

Combined with new antennas that are under constructio, e-VLBI with the new correlators could also be much more flexible and ready to observe at any time with the most optimal array, never compromising the optimal scientific return, yet providing immediate feedback as well. This is the VLBI facility that future astronomers, SKA users, will want to use.