Current Status of Shanghai VLBI Correlator

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Abstract Shanghai Astronomical Observatory has upgraded its DiFX cluster to a 420 cpu cores and a 432 TB storage system at the end of 2014. An international network connection for the raw data transfer has also been established. The routine operations for IVS sessions including CRF, AOV and APSG series began in early 2015. In addition to the IVS observations, the correlator is dedicated to astrophysical and astrometric programs with the Chinese VLBI network and international joint VLBI observations. It also worked with the new-built Tianma 65-m radio telescope and successfully found the fringes as high as at X/Ka and Q bands in late 2015. A more powerful platform is planned for the high data rate and massive data correlation tasks in the future.

Keywords VLBI correlator, IVS, astrometry, radio telescope

1 Introduction

The VLBI group in Shanghai Astronomical Observatory (SHAO) has a long history of the development with the VLBI correlator. The domestic software correlator and hardware correlator are mainly developed and applied for the VLBI tracking system in the Chinese deep space missions. The worldwide open source software correlator called DiFX is adopt at SHAO in 2012 and works as a dedicated correlator for astrophysics and geodesy. The computer cluster and the data storage system of the DiFX correlator has been upgraded in the end of 2014. It has 420 CPU cores and 432 TB storage capacity (Figure 1). An international high speed network connection for the raw data transfer among main correlators and geodetic stations is established. Beginning in 2015, the DiFX correlator is also served as an IVS correlator. By now, more than 10 IVS sessions such as CRF-, AOV-, APSG-, CRDS-series and a few Australian geodetic VLBI sessions have been processed by the plantform.

Besides of the IVS correlations, the plantform also serves for the astrophysical and astrometric programs conducted with the Chinese VLBI network (CVN) and international joint VLBI observations. Meanwhile, the new-built Tianma 65-m telescope will cover the frequency range from the L to the Q band together with two dual-frequency receivers in S/X and X/Ka. The DiFX correlator successfully worked with the Tianma
65-m and found the fringes high to the X/Ka and Q bands in late 2015.

2 Performances and operations

2.1 Platform performances

The computer cluster shown in Fig.1 is divided into two groups for the routine operations. Each head node manages 10 computing nodes, 200 CPU cores in total. The main features including the hardwares, the softwares and the network conditions are listed as follows. The maximum correlation speed is around 1 Gbps per station when processing 10 stations simultaneously (Figure 2). There are more than 6 staff (about 50% working time) for different parts of the operations from data delivery to giving out the final outputs.

- Correlator: DiFX-2.2/2.3/2.4/trunk
  - Post-processing software: HOPS 3.9/3.10/3.11/3.12
- Head nodes: DELL R820 (E5-4610 CPU, 2.4 GHz, 2*6 cores), 64 GB Memory DELL R730 (E5-2623 CPU, 3.0 GHz, 2*4 cores), 64 GB Memory
- Computing nodes: 20 DELL R630 nodes, 400 cores in total, 2 socket Intel E5-2660 CPU (2.6 GHz, 10 cores), 64 GB Memory
- I/O nodes: RAID6, 432 TB raw storage capacity
- Mark5 units: 3 Mark5A and 3 Mark5B.
- 56 Gb Infiniband for internal computing network connection
- 1/10 Gb Ethernet for internal & external network connection

2.2 e-transfer

In order to process global IVS sessions, the network links to Fortzela, HartRAO, Hobart, Kashima, Noto, Sejong stations and Bonn correlator have been established (Figure 3). However, the links are not connected in a real time mode, some time slots of connections are negotiated before the data transfer. The two Shanghai VLBI stations are in a 10 Gb link to the VLBI center while other CVN stations are in a much lower rate connection. Most of the high data rate and long duration recording experiments are still through shipment of the diskpacks in CVN.

Fig. 3 Network conditions at Shanghai VLBI center.

2.3 Statistics of correlation operations

Some comparisons of the outputs after correlation and post-processing were made between the Shanghai DiFX correlator and the Bonn DiFX correlator in late 2014. The RMS of the group delay differences in the X band extracted from an S/X session were within a few picoseconds. In early 2016, a similar comparison was made between the two correlators. The results listed in Table 1 implied the group delay of the two correlator outputs coincided at picosecond level. Besides of serving for the global IVS sessions, the DiFX correlator is open to make correlations for the astrophysical and astrometric programs with CVN, east Asian and Australian joint VLBI observations. Table 2 lists the summary of the correlations in details.
Table 1 Comparison results of Shanghai DiFX and Bonn DiFX correlators.

| Baseline | S band | X band |
|---------|--------|--------|
|         | SNR    | Group delay (ps) | Rate (ps/s) | SNR    | Group delay (ps) | Rate (ps/s) |
| Ny-Ts   | 1      | 2.4    | 0.0127 | 0.992 | 1.1    | 0.0085 |
| Ny-Wn   | 1      | 5.6    | 0.0208 | 1.002 | 1.6    | 0.0095 |
| Ny-Wz   | 1      | 3.8    | 0.0156 | 0.994 | 0.9    | 0.0041 |
| Ts-Wn   | 1      | 4.6    | 0.0198 | 1     | 1.7    | 0.0091 |
| Ts-Wz   | 1      | 2.8    | 0.0113 | 0.994 | 0.9    | 0.0063 |

Table 2 Summary of correlations processed.

| Session Code | Observation Type | Times in a year | Stations participated | Recording rate |
|--------------|-----------------|-----------------|-----------------------|----------------|
| AUS-(AST,GEO)| Geodesy         | 12 (2016)       | Australian, more than 4 st. | 1024 Mbps |
| CVN-(CN)     | Geodesy         | 4               | CVN, Js and Ks³, more than 3 st. | 512 Mbps |
| CVN-(PSR)    | Pulsar Astrometry | not fixed | CVN, 3 or 4 st. | 1024 Mbps |
| CVN/EAVN     | Astrophysics    | not fixed       | CVN or EAVN, more than 4 st. | 1024 Mbps |
| IVS-(AOV,APSG,CRDS,CRF,RD) | Geodesy   | >10             | Global, up to more than 10 st. | 256/1024 Mbps |
| VEPS         | Astrometry      | 6               | east Asian and Australian, 3 or 4 st. | 2048 Mbps |

3 Some results

3.1 IVS and astrometric programs

There were fifteen IVS sessions including eight CRF, three AOV, two APSG, one AUG and one CRDS series processed and given out databases to the analysis center by the Shanghai correlator until now. The main time consumption was in the raw data delivery. Three CVN stations including Kunming 40-m, Shanghai 25-m and Urumqi 26-m participate ordinary IVS sessions. The accuracy of their station positions achieves a few centimeters due to these long term global geodetic sessions. It helps to carry out some astrometric programs based on the three stations. As also presented in this proceeding, an ecliptic plane survey program was based on the above three stations together with one more stations from Hobart, Kashima and Sejong. The feasibility of DiFX correlator made it possible to have different quantifications and baseband bandwidth among different stations. In the first phase of observations, there were 435 target sources detected in three or more observations among more than 2000 candidates in the source pool. The detection rate was near 20%.

A pulsar astrometry program has conducted with the S band receivers in the three stations. Five epoch phase-referenced VLBI positioning of the millisecond pulsar B1937+21 were carried out from 2012 to 2015. The signal to noise ratio of the pulsar signal was improved by pulsar gating during the correlations. After EOP, station positions and ionospheric delay corrections, the best fitted proper motion in RA and DEC were $0.1237\pm0.18$ mas/yr and $-0.2585\pm0.52$ mas/yr with a problematic parallax $\Pi = -0.678$ mas. Regardless of the parallax, the proper motion parameters were consistent with the 15.5 year timing solutions, $0.087(16)$ mas/yr in RA and $-0.41(3)$ mas/yr in DEC. A deeper analysis is needed for the error mitigation.

3.2 Tianma 65-m related

The new-built Tianma 65-m radio telescope is about 6.1 km away from the Shanghai 25-m telescope. The receivers installed make it have a continuous frequency coverage from the L band to the Q band. Two dual-frequency receivers in S/X and X/Ka bands play an important role in the geodetic activities. Besides of single dish observations, Tianma 65-m is also an important site for the VLBI community. Some joint observations with KaVA, EVN and VLBA have already been carried out in the low frequency bands. The fringes at high frequency bands including the X/Ka and the Q were found in late 2015 (Figure 5-a, 5-b). The X/Ka experiment was carried out with Tianma-Wettz13n-Zelen13m in RU0197 session. While the Q band experiment was a Tianma-KaVA joint observation, an ad-hoc room temper-

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1 The ratio of SNR.
2 The WRMS of the differences in group delay and rate.
3 Js: Jiamusi, Ks: Kashi, two deep space stations of China.
Acknowledgements

The work is supported by the National Natural Science Foundation of China (No.Y247021001) and the Joint Funds of the National Natural Science Foundation of China (No.U1331205).

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4 Conclusions

The DiFX plantform at SHAO is dedicated to the astrophysical and the geodetic VLBI observations. It serves as an IVS correlator since 2015. The planform is also open to the CVN and joint international VLBI observations. Concerning to the next generation broad band and dual polarization VLBI observations, the Shanghai correlator will continue to make its contributions to the data correlation and processing. For the future high data rate and massive data correlations, current network condition will be one of the bottlenecks and must be improved. A more powerful platform with a high performance computing cluster and a competent storage system is also needed.