Shanghai VLBI Correlator

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Abstract This report summarizes the activities of the Shanghai VLBI Correlator during 2015 and 2016. Highlights include the intensive and reliable DiFX operation, growing e-VLBI connection with international stations, conversion of the CVN correlator output to the Mark IV file system, fringe tests for Tianma65, and running PIMA analysis.

1 Introduction

The Shanghai VLBI Correlator is hosted and operated by the Shanghai Astronomical Observatory (SHAO), at the Chinese Academy of Sciences (CAS). It is located at the Sheshan campus, about 40 kilometers from the Xujiahui headquarters of SHAO. The Shanghai correlator plays a leading role in the data processing of the Chinese VLBI Network (CVN), inclusive of the CMONOC project for monitoring the Chinese regional crustal movement and the Chinese deep space exploration project for spacecraft tracking.

As shown in Figure 1, Shanghai (including Seshan25 and Tianma65), Kunming, and Urumqi participate in some domestic geodetic and astronomical sessions, while the Beijing station is mainly used for spacecraft data downlink and VLBI tracking. A few joint observations with the Chinese deep space stations Kashi and Jiamus were also performed.

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Shanghai Correlator

IVS 2015+2016 Biennial Report

The Shanghai correlator was accepted as an IVS correlator in March 2012. It began to correlate the IVS data using the DiFX in 2015. In the long run, our goal is to correlate a weekly IVS observing session on a regular basis.

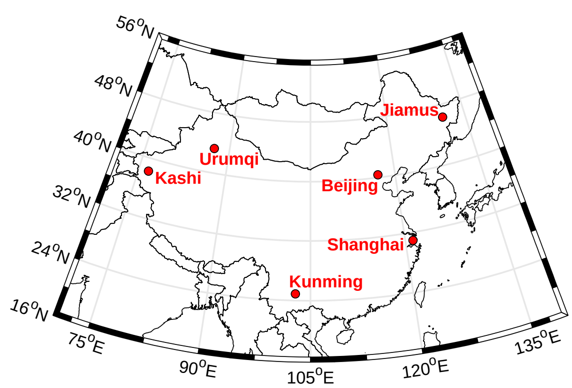

Fig. 1 Distribution of the VLBI stations in China.

2 Component Description

We are operating two types of correlators. The CVN correlator developed by our own staff has been operational since 2006. It is mainly used for spacecraft VLBI tracking in the Chang'E lunar exploration project by producing differential VLBI observables. The data latency is less than one minute in real time mode, and the typical accuracy is better than 1 ns. It has also been used to correlate a few tens of CMONOC geodetic sessions before 2014. The other one is the DiFX software correlator, which is dedicated to astrophysical and geodetic data correlation.

The DiFX software was installed on a powerful hardware platform in December 2014, with a 420 core cluster system and a 430 TB storage space, as shown in Figure 2. This new platform is very important for the IVS data correlation. In the routine operations, half of the computing and the storage sources are assigned to the geodetic correlation tasks. Features of the DiFX cluster system are listed as follows:

- DiFX 2.2/2.3/2.4/trunk, 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, two socket Intel E5-2660 CPU (2.6 GHz, ten cores), 64 GB Memory, 400 cores in total
- I/O nodes: RAID6, 432 TB raw storage capacity
- Mark 5 units: three Mark 5A and three Mark 5B.
- 56 G Infiniband for internal computing network connection
- 1/10 G Ethernet for internal and external network connection

Fig. 2 DiFX cluster system and Mark 5A/B units.

3 Staff

The people involved in the operation and development of the Shanghai Correlator are listed below.

- Weimin Zheng: group head, software correlator, and VLBI terminal development
- Xiuzhong Zhang: CDAS and other technique development
- Fengchun Shu: scheduler, experiment oversight, and CDAS evaluation
- Zhong Chen: e-VLBI and cluster administration
- Wu Jiang: DiFX operation and experiment support
- Tianyu Jiang: DiFX operation and experiment support
- Wenbin Wang: media library and experiment support
- Zhanghu Chu: operator and experiment support
- Renjie Zhu: CDAS development
- Zhijun Xu: FPGA programming and hardware correlator development
- Juan Zhang: software correlator development and maintenance
- Li Tong: software correlator development and maintenance
- Lei Liu: post-doctoral fellow and software correlator development

4 Summary of Activities

4.1 DiFX Correlation

For regular IVS data correlation, we use the DiFX, HOPS, and Dbedit software to generate Mark III database files and submit them to the IVS Data Center, in a similar way that the other IVS correlators do.

In order to make the correlation results reliable, we made comparisons with the Bonn correlator of the CRF86 and CRF87 sessions in 2015 and the K16095 session in 2016. Although the two correlators used different parameter configurations, the total delay observables can be used for comparisons. The results show that the WRMS of group delay differences is less than 2 ps at X-band and less than 8 ps at S-band, far below the measurement thermal noises.

4.2 e-VLBI

The network link to Seshan25 and Tianma65 is 10 Gbps. The network link to the Urumqi, Kunming, and Beijing stations is 155 Mbps for domestic e-VLBI observations. For the future Chang'e 5 lunar mission, we have planned to make data transfer at a 128 Mbps data rate for each station.

In order to process IVS global sessions, we have established the network link to most of the IVS stations, the Bonn correlator, and the Haystack correlator as well. The maximum data rate is 1 Gbps. All international stations except Kokee e-transfer data to Shanghai.

4.3 Development of the CVN Software Correlator

We implemented offline software, *cvn2mk4*, which can convert the CVN correlator output to the Mark IV file system, so that the correlation results could be processed by HOPS. Other offline software, *cvn2fits*, can make the CVN correlator output to be loaded into the AIPS for imaging.

In 2016, we processed the K14349 and cn1502 sessions with the CVN software correlator and the DiFX respectively. Then the correlator output was processed by the HOPS. Comparisons were made of the SNR, group delay, and delay rate. The results indicated that the group delay and rate observables agree well, while the SNRs produced from the CVN correlator are slightly less than those from the DiFX correlator. The comparison of SNR differences for K14349 is shown in Figure 3.

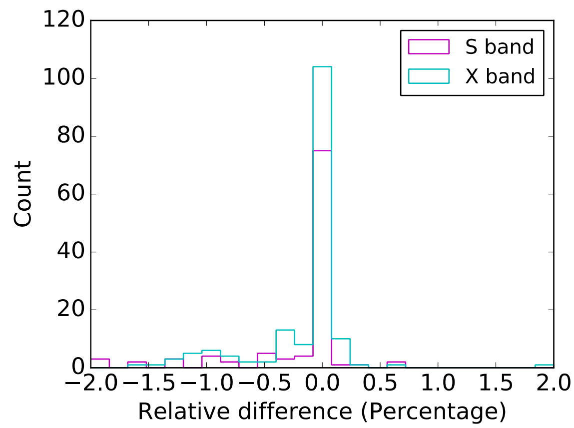

Fig. 3 Histogram of the relative SNR difference of the CVN correlator with repect to the DiFX correlator in K14349.

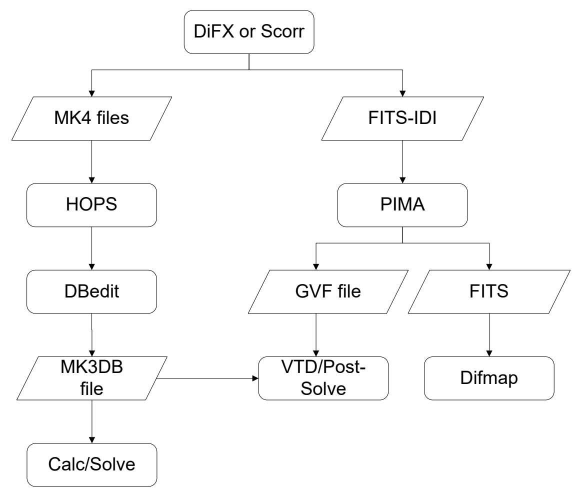

Fig. 4 Data flowchart based on the HOPS and PIMA software.

4.4 Running PIMA Analysis

The VLBI post-correlation analysis software PIMA was developed in recent years, aimed at absolute astrometry and radio imaging with high efficiency and weak fringe detection. We installed the PIMA in 2015, which performs phase calibration, complex bandpass calibration, and fringe search with advanced methods.

For some VLBI experiments correlated at SHAO, such as APSG, AOV, and VEPS sessions, we generated FITS-IDI formatted data and ran PIMA analysis regularly. Figure 4 shows the data flowchart based on the HOPS and PIMA software.

4.5 VEPS

We conducted 13 24-hour VEPS (VLBI Ecliptic Plane Survey) sessions in the search mode. Seshan25, Kunming, and Urumqi are core participating stations, while Kashim34, Hobart26, and Sejong took part in the observations on an ad hoc basis. The data volume for each station is approximately 16 TB, eight times bigger than that recorded in regular IVS geodetic sessions, so the data correlation of one VEPS session usually took more than 24 hours.

4.6 Experiments Correlated

Within the framework of the IVS, we correlated 11 sessions in 2015 and 28 sessions in 2016. We also organized a few Chinese domestic geodetic VLBI experiments and some VEPS observations. More details can be found in Table 1.

Table 1 Statistics of experiments correlated.

Session Name	2015	2016
AOV	3	3
APSG	2	2
AUS-AST	0	7
AUS-GEO	0	6
IVS-CRF	6	6
IVS-CRDS	0	3
IVS-R&D	0	1
CN-GEO	5	4
VEPS	6	7

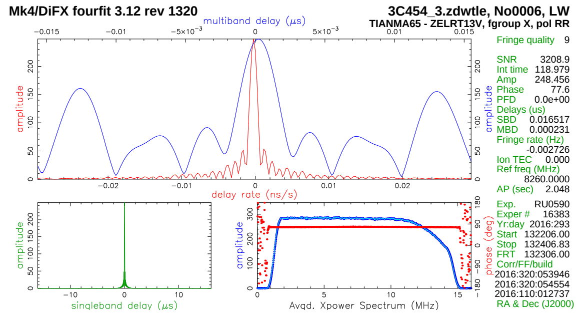

Fig. 5 X-band fringes on the baseline Tianma65-Zelen13m.

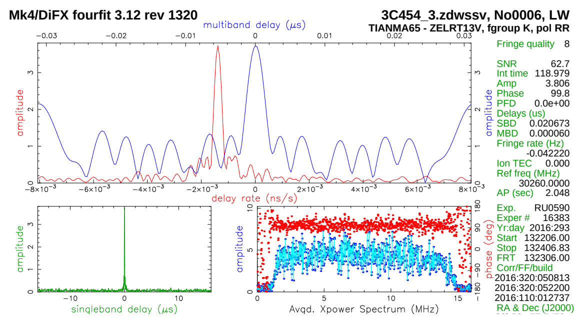

Fig. 6 Ka-band fringes on the baseline Tianma65-Zelen13m.

4.7 Fringe Tests for Tianma65

We conducted an X/Ka-band fringe test with Tianma65, Badar13m, Zelen13m, and Wettz13n on October 28, 2015. Fringes to Tianma65 were found at Ka-band but not X-band. After a few more fringe tests on the baseline Tianma65-Seshan25, we conducted another X/Ka-band fringe test with Tianma65, Badar13m, and Zelen13m on October 19, 2016. Tianma65 used the standard GEO mode, i.e., ten IF channels spread over Ka-band and six IF channels spead over X-band. The bandwidth per IF channel is 16 MHz. The Russian stations used two IFs with 512 MHz bandwidth each, recorded in VDIF format. We made correlations with the DiFX zoom band mode. Fringes to Tianma65 were obtained at X/Ka dual band for the first time, as shown in Figure 5 and Figure 6.

4.8 DiFX Meeting

The 10th DiFX Users and Developers Meeting was held in Shanghai, October 30 – November 3, 2016. More than 20 participants from nine countries and regions were hosted by our correlator operation team (Figure 7). There were 21 oral talks presented at the users meeting, which was arranged for the first two days. Then the developers worked together in the next three days for planning the DiFX updates. During the meeting, an excursion was arranged to visit the Shanghai correlator located at the Sheshan campus and the Tianma Radio Telescope.

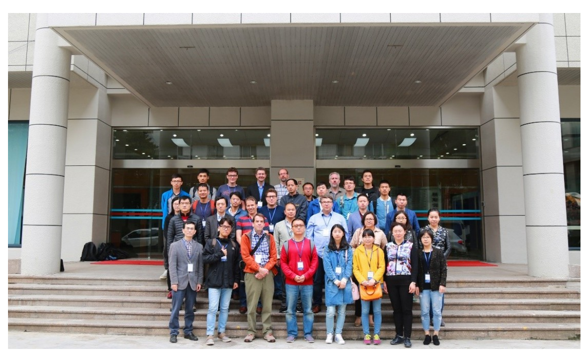

Fig. 7 Participants of the 10th DiFX Users and Developers Meeting.

5 Future Plans

We plan to correlate 31 observing sessions assigned by the IVS in 2017. To ensure that the final results are reliable and convincing, we plan to make comparisons with other IVS correlators, focused on the use of multi-tone phase calibration. We will continue to support the data correlation of the Chinese domestic VLBI observations with a growing number of experiments and stations.

We will continue to develop the CVN software correlator in order to use it to process some geodetic experiments. Construction of the Seshan VGOS station is scheduled to be finished in 2017. It will be challenging to obtain real VGOS data for trial correlation.

Acknowledgements

We are very grateful to Alessandra Bertarini for commissioning our DiFX operation. We also acknowledge the National Natural Science Foundation of China (NSFC) for funding projects VEPS (U1331205) and BBD measurement (11573056).