Tsukuba VLBI Correlator

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Abstract This report summarizes the activities of the Tsukuba VLBI Correlator during 2015 and 2016. The weekend IVS Intensive (INT-2) sessions and the Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) sessions were regularly processed using the K5/VSSP correlation software. In addition, the Japanese domestic VLBI observations (JADE) were also correlated in 2015.

1 Introduction

The Tsukuba VLBI Correlator, located in Tsukuba, Japan, is operated by the Geospatial Information Authority of Japan (GSI). It is fully devoted to processing geodetic VLBI observations of the International VLBI Service for Geodesy and Astrometry (IVS). All of the weekend IVS Intensive (INT-2) sessions for UT1-UTC (= dUT1) determination and the Japanese domestic VLBI observations for geodesy called JADE organized by GSI were processed at the Tsukuba VLBI Correlator. Moreover, half of the Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) sessions, which started as regular sessions in 2015, were also correlated. The K5/VSSP correlation software developed by the National Institute of Information and Communications Technology (NICT) is used for all processing.

1. Geospatial Information Authority of Japan
2. Advanced Engineering Service Co., Ltd.

2 Component Description

2.1 e-VLBI

The Tsukuba VLBI Correlator has been connected to a broadband network, and all of the observed VLBI data are delivered via the network. The Tsukuba VLBI Correlator has a 10-Gbps dedicated link to the SINET5 operated by the National Institute of Informatics (NII), which is connected to several research networks in the world such as Internet2 in the U.S., GÉANT2 in Europe, and TEIN4 at Singapore. It enabled us to transfer a massive amount of data between the Tsukuba VLBI Correlator and the overseas IVS Components. The Ishioka VGOS Station has also been connected to the Tsukuba VLBI Correlator and SINET5 with a 10-Gbps dedicated cable since 2014.

2.2 K5/VSSP Correlation Software

The K5/VSSP correlation software consists of several programs for the calculation of a priori values of delay and delay rate (*apri_calc*), for the correlation processing for all observations (*fx_cor or cor*), and for monitoring the results of the correlation processing by performing a so-called "coarse search" (*sdelay*), followed by several utilities such as *Komb* for bandwidth synthesis [1]. All of these programs were developed and have been maintained by NICT. The K5/VSSP correlation software can be used not only for K5 data processing but also for Mark 5 data processing by using the data format conversion program (*m5tok5*).

Table 1 Correlator hardware capabilities.

	Main system	**Backup System**
Number of servers	16 - 14 for correlation processing - 2 for controlling correlation processing	44 - 16 for correlation processing - 2 for controlling correlation processing - 26 for data storage
Operating System	Red Hat Enterprise Linux 6.3	CentOS version 5.5
CPU	Intel Xeon X5687 @3.60GHz quad CPU x 2	Intel Xeon X3360 @2.83 GHz quad CPU Intel Xeon 5160 @3.00 GHz dual CPU x 2 Intel Xeon X3480 @3.07 GHz quad CPU Intel Xeon @3.80 GHz CPU x 2
Total storage capacity	Data Direct Networks storage: 513 Tbytes	Lustre File System: 30 Tbytes
Network	10 Gbps dedicated line connected to SINET5 by NII	

The following are processes of the K5 correlation and programs used in each process.

1. Transferring data from network stations to the correlator (*tsunami and tsunamid*, or *jive5ab*).
2. Data format conversion from Mark 5 to K5 (*m5tok5 or m5btok5*).
3. Preparation of a priori parameter files (*apri_calc*).
4. Fringe search to find a clock offset at each pair of stations (*fx_cor or cor*).
5. Running correlation processing for all observations (*fx_cor or cor*).
6. Coarse search for estimating residual delays and delay rates, then plotting these values on a 3-D diagram (*sdelay*).
7. Bandwidth synthesis to derive multi-band delays (*komb*), then the creation, by *MK3TOOLS*, of Mark III databases to be submitted to the IVS Data Centers.

The correlation and analysis management programs developed by GSI can run the above processes consecutively and ultra-rapidly. The program for the management of data transfer *rapid_transfer* accesses a data server in an observing station, executes *tsunamid* there, and then executes *tsunami* to transfer data automatically at the correlator side when an observation starts. The data is converted from Mark 5 to K5 format by a program *rapid_conv* as necessary. *Rapid_cor* is a program that performs a fringe search for each baseline according to the clock information of each station written in the FS log. Once the fringe is detected, the main correlation processing is run sequentially with the clock offset and rate found in the fringe search until the last observation. *Rapid_komb* executes successive runs of *komb* for bandwidth synthesis processing. The fully automated VLBI analysis software *c5++* developed by NICT can read the komb output files directly and derives a VLBI solution [2]. *Rapid_c5pp*, which provides an interface for *c5++*, makes a configuration file for *c5++* automatically and executes analysis.

2.3 Correlator Hardware Capabilities

The hardware supporting the activities of the Tsukuba VLBI Correlator is summarized in Table 1. All of these pieces of equipment are general purpose and commercially available products. It means that no dedicated hardware is required in the K5 correlation processing. In 2014, IBM System X3650 servers and a Data Direct Networks storage system with a capacity of 513 TB were incorporated into the main correlation processing (Figure 1). It shortens the time of processing of correlation by about half. The existing system is also available as a backup system (Figure 2).

3 Staff

The technical staff at the Tsukuba VLBI Correlator are:

- **Takahiro Wakasugi** — correlator/analysis chief, management.
- **Tetsuya Hara** (AES) — correlator/analysis operator, software development.

Fig. 1 View of the main system (data processing servers and storage) at the Tsukuba VLBI Correlator.

4 Correlator Operations

4.1 IVS Intensive for UT1-UTC

In total, 104 and 115 Intensive sessions that were observed on weekends were processed at the Tsukuba Correlator in 2015 and 2016, respectively. The details are described in Table 2. The observed data at Wettzell are transferred to the Tsukuba Correlator in near real-time with the Tsunami UDP protocol and are converted to the K5 format immediately. The observed data at the Tsukuba station are also transferred to the correlator at once. The whole process from data transfer through analysis is implemented by the *rapid_* programs (see Section 2.2), and a dUT1 solution of the Tsukuba–Wettzell baseline can be derived within a few minutes after the end of the last scan of the session. In addition, we started the Ishioka–Wettzell baseline observations called Q-Intensive from October 2016 in order to validate dUT1 solutions with the new baseline. We confirmed that all of the processes were working well for Ishioka with a slight modification.

Table 2 Intensive sessions processed at the Tsukuba Correlator.

2015	Baseline	Period	# of sessions
Intensive 2	TsWz	Jan 03 – Dec 27	99
	KbWz	Oct 24, Oct 25	2
Intensive 3	NyShTsWnWz	Oct12	1
	NyTsWnWz	Nov 30, Dec 07	2
Total			104
2016	**Baseline**	**Period**	**# of sessions**
Intensive 2	TsWz	Jan 02 – Dec 31	88
	IsTsWz	Oct 08 – Dec 18	12
	IsWz	Oct 07 – Dec 27	15
Total			115

4.2 AOV

AOV was established in 2014 and started regular observations from 2015. Six AOV sessions were performed every year, and the Tsukuba Correlator took charge of the correlation of half of the sessions every year. Most of the data were transferred via the broadband network from not only Japan, but also China, Korea, Australia, and New Zealand, while the data of Syowa were only

Fig. 2 View of the backup system.

shipped to Japan. In addition, some stations sent data in real-time for ultra-rapid EOP estimation testing.

4.3 JADE and JAXA

JADE is a domestic geodetic VLBI series involving four GSI stations (Tsukuba, Ishioka, Aira, and Chichijima), three NICT stations (Kashima 34-m, Kashima 11-m, and Koganei 11-m), and one VERA station of the National Astronomical Observatory of Japan (NAOJ) located in Mizusawa. 18 JADE sessions were correlated in 2015. Because Aira and Chichijima were closed in 2015, JADE sessions were also finished at the end of 2015. The JAXA sessions are conducted separately from JADE, including JAXA stations, such as Usuda, in order to determine the global positions of the stations within ITRF. One JAXA session was processed in each year.

5 Outlook

We will continue to process the IVS Intensive sessions. For more stable operation, we will make further improvements to the *rapid_* programs and maintain the hardware and the network. We will also process the observed data of AOV sessions to play a major role in AOV as a correlator. Furthermore, we will try to process broadband observation data in order to explore the possibility of being a future VGOS correlator.

References

1. Kondo, T., et al.: Development of the K5/VSSP System, *Journal of the Geodetic Society of Japan*, **54**(4), 233–248, 2008.
2. Hobiger, T., et al.: Fully automated VLBI analysis with c5++ for ultra-rapid determination of UT1, *Earth Planets Space*, **62**, 933–937, 2010.