Tsukuba VLBI Correlator

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Abstract This report summarizes the activities of the Tsukuba VLBI Correlator during 2017 and 2018. The correlator was regularly involved in the weekend IVS Intensive (INT-2) sessions as well as the Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) sessions using the K5/VSSP correlation software.

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) estimation and half of the Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) sessions, which began as regular IVS sessions in 2015, were processed at the correlator. The K5/VSSP correlation software developed by the National Institute of Information and Communications Technology (NICT) is used for all processing.

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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 basically. The 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 correlator and overseas IVS components. The Ishioka VLBI station has also been connected to the correlator and *SINET5* with a 10 Gbps dedicated cable since 2014.

2.2 K5/VSSP Correlation Software

The K5/VSSP correlation software, which was developed and has been maintained by NICT, is adopted at the correlator. The 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_new or cor_new*), 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 the bandwidth synthesis [1]. The software can handle not only K5 format data but also Mark 5B or VDIF format data without format conversion in the latest version.

Table 1 Correlator hardware capabilities.

	Main system	**Backup System**
Number of servers	16 - 14 for correlation processing - 2 for controlling correlation processing	5 - 2 for correlation processing - 2 for controlling correlation processing - 1 for data storage
Operating System	Red Hat Enterprise Linux 6.3	CentOS version 6.9 and 7.4
CPU	Intel Xeon X5687 @3.60GHz 4 cores x 2	Intel Xeon X3360 @2.83 GHz 4 cores Intel Xeon Gold6130 @2.10 GHz 16 cores x 2 Intel Xeon E5-2609v4 @1.70 GHz 8 cores x 2
Total storage capacity	513 Tbytes	273 Tbytes
Network	10 Gbps dedicated line connected to SINET5 by NII	

2.3 Correlation Procedure

The following are typical correlation processes at the correlator and programs used in each process.

1. Transferring data from network stations to the correlator (*tsunami and tsunamid*, or *jive5ab*).
2. Preparation of a priori parameter files (*apri_calc*).
3. Fringe search to find a clock offset at each pair of stations (*fx_cor_new or cor_new*).
4. Running correlation processing for all observations (*fx_cor_new or cor_new*).
5. Coarse search for estimating residual delay and delay rate, and plotting them on a 3-D diagram (*sdelay*).
6. Bandwidth synthesis to derive a multi-band delay (*komb*).
7. Database creation to be submitted to IVS Data Centers (*vgosDbMake* for vgosDb format or *MK3TOOLS* for Mark III format).

The correlation and analysis management programs developed by GSI can run the above processes consecutively and automatically. 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 concurrently with the start of the session as needed. *Rapid_cor* is a program to search for a fringe for each baseline based on the clock information of each station written in the FS log, as well as the station positions and source coordinates described in the schedule file and external a priori earth orientation parameters. Once the fringe is detected, the main correlation processing runs one after another with the clock offset and rate information derived from the fringe search process until the last observation. *Rapid_komb* executes *komb* on the stream of correlation outputs for bandwidth synthesis process. For the weekend Intensive sessions, *rapid_c5pp*, which gives an interface to VLBI analysis software *c5++*, executes analysis automatically as the bandwidth synthesis process finishes and delivers the result to the community (refer to the report "Tsukuba VLBI Analysis Center" in this volume for more details). The database creation is carried out manually with *vgosDbMake* for the vgosDb format or with *MK3TOOLS* for the Mark III format to be submitted to IVS Data Centers [2] [3].

2.4 Correlator Hardware Capabilities

The hardware supporting the activities of the correlator is summarized in Table 1. All these pieces of equipment are general purpose and commercially available products. It means that no dedicated hardware is required in the K5 correlation processing. The main system consists of 16 IBM X3650 servers and a Data Direct Networks storage system with a capacity of 513 TB (Figure 1). In 2018, the backup system consisting of five servers and 273 TB RAID data storage was installed and has been utilized for some test purposes.

3 Staff

The technical staff members at the correlator are:

- **Takahiro Wakasugi** — correlator/analysis chief, management.
- **Michiko Umei** — correlator/analysis operator, coordination.

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

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

4 Correlator Operations

4.1 IVS Intensive for UT1-UTC

All of the weekend Intensive series (INT-2) were processed at the correlator automatically in near real time using the *rapid_* programs (see Section 2.3). The number of sessions processed in 2017 and 2018 is listed in Table 2. Ishioka in Japan and Wettzell 20 m in Germany have participated in INT-2 sessions usually. On the other hand, some telescopes such as Kokee Park in Hawaii, U.S., Sheshan in China, or Kashima 34 m in Japan were involved when Ishioka was not available during the VGOS test period for a few months a year. The 13.2-m Wettzell North Telescope also filled in during the absence of Wettzell 20 m sometimes. In addition, a few INT-3 sessions on Monday were correlated on behalf of the Bonn Correlator. Please refer to the report "Tsukuba VLBI Analysis Center" in this volume for results and more details.

Table 2 Intensive sessions processed at the Tsukuba Correlator.

2017	Baseline	Period	# of sessions
Intensive 2	IsWz	Jan 08 – Dec 31	79
	IsWn	Aug 05 – Aug 06	2
	KkWz	Jun 03 – Dec 10	8
	ShWz	Nov 04 – Nov 12	4
	KbWz	Dec 16	1
Intensive 3	IsNyWnWz	Oct 30	1
Total			95
2018	Baseline	Period	# of sessions
Intensive 2	IsWz	Jan 07 – Dec 29	59
	IsWn	Mar 17 – Mar 18	2
	KkWz	Jun 09 – Sep 30	18
	KkWn	Aug 11	1
	ShWz	Jul 28 – Aug 26	4
	ShWn	Aug 05	1
	KbWz	Mar 10 – Mar 11	2
Intensive 3	IsWnWz	Dec 24	1
Total			88

4.2 IVS AOV sessions

The Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) is a regional subgroup of the IVS es-

tablished in 2014 to foster and encourage closer collaboration in VLBI in the Asia-Oceania region. The dedicated VLBI experiments started in 2015 regularly once every two months, and the number of sessions has increased to 12 sessions in a year since 2018. Correlation tasks are shared by the Tsukuba VLBI Correlator and the Shanghai Correlator operated by Shanghai Astronomical Observatory (SHAO). The number of sessions processed at the Tsukuba VLBI Correlator in 2017 and 2018 is listed in Table 3. 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 in Antarctica were only shipped to Japan. In addition, the correlator works on the intensification of giving feedback to stations and schedulers based on the correlation results in order to improve the data quality of the AOV sessions through the dedicated mailing list for the AOV operation.

Table 3 AOV sessions processed at the Tsukuba Correlator.

Year	Name	Date	Stations	Data Rate
2017	AOV013	Jan 16	HbK1KeKgKmKvSyUrVmYg	128 Mbps
	AOV016	Apr 11	HbIsKeKmKvShUrVmYg	1 Gbps
	AOV018	Nov 15	KbKeKmKvShUrWwYg	1 Gbps
2018	AOV020	Feb 27	IsK1KeKgSyWwYg	128 Mbps
	AOV023	May 21	HoIsK1KgVmWwYg	1 Gbps
	AOV024	Jun 19	HoK1KeKvSyWwYg	128 Mbps
	AOV028	Oct 16	HoIsKbKeKvVmWwYg	1 Gbps
	AOV030	Dec 11	HoIsKeKvWwYg	1 Gbps

4.3 Procedure Updates

There were several major updates to the correlation procedure during this period.

- **Station Clock Update**

The handling of station clocks has direct consequences for the values of the UT1 estimation [4]. The station clock information was updated properly following instructions of the IVS.

- **Transition to vgosDb Format**

The database creation procedure was modified in response to the transition of database format from Mark III style to vgosDb style. The database creation software *vgosDbMake*, which can handle the *Komb* output directly, was installed and incorporated into the ordinary procedure. The Mark III format databases are also created based on requests from a few Analysis Centers.

- **Capability of Dealing with VDIF and Mark 5B Format**

The latest version of the K5/VSSP correlation software can handle not only K5 format but also Mark 5B and VDIF format without format conversion. The correlation and analysis management programs developed by GSI obtained the ability to deal with Mark 5B and VDIF format by slight modification of programs and have been adopted for the operational INT-2 processing since Q18335 in December 2018. This modification contributes to saving effort and reducing the amount of data generated by the data format conversion.

5 Outlook

We will continue to process the IVS Intensive sessions and AOV sessions. For more stable operation of especially near real time processing, we will make further improvements to the *rapid_* programs and maintain the hardware and network. Furthermore, we will introduce the DiFX correlation software for the correlation of VGOS data.

References

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