Recent VLBI technology at NICT and VLBI2010

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ABSTRACT

Recent technology developments at NICT are categorized into (a) e-VLBI technique, which is a technique that data are transferred to a correlation site via high-speed communication lines like the Internet, (b) software correlator for a practical use, and (c) small antenna system to verify the wide band receiving system proposed in VLBI2010 which is the recommendation to the next generation VLBI system compiled by the IVS (International VLBI Service for Geodesy and Astrometry). E-VLBI technique and software correlator have enabled us to measure UT1 with the latency of less than 30 minutes after the last observation. Wide-band receiving system realizes the use of small antenna for geodetic VLBI.

Keywords: e-VLBI, VLBI2010

1. Introduction

Recently, e-VLBI technique, which is a technique that data are transferred to a correlation site via high-speed communication lines like the Internet, comes into practical use. Combination of e-VLBI and an automated pipeline data processing has enabled us to obtain UT1 with the minimum latency of 30 minutes after a VLBI session is over since April 2007. Now latency is further shortened to be less than 4 minutes. In parallel to the development of e-VLBI technique, the development of digital base band converter (DBBC) has been actively promoted at technology development centers (TDCs) of IVS (International VLBI Service for Geodesy and Astrometry). NICT is one of IVS-TDCs and has been developing a variety of VLBI instruments and software. In the mean time, the current geodetic VLBI system was constructed mostly in 1980's. Gradually it becomes difficult to keep the accuracy due to increasing radio interference signals (RFI). Old and slow-slew rate antennas also make it difficult to adopt a new observation strategy such as increase of the number of observation in a day. To overcome these situations IVS started a discussion in 2003 about the next generation geodetic VLBI system called VLBI2010, and the first report was issued in 2005. Discussion is still continued. In this report, recent VLBI technology development at NICT is introduced, and brief introduction of VLBI2010 is also included.

2. Ultra-rapid UT1 measurement

National Institute of Information and Communications Technology (NICT), Japan has been developing "ultra-rapid UT1 measurement" system by using an e-VLBI technique in collaboration with Geographical

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Survey Institute, (GSI Tsukuba, Japan), Onsala Space Observatory (Sweden), and Metsähovi Radio Observatory (Finland). Locations of these stations and a block diagram of data flow and data processing are indicated in Fig.1. NICT and Metsähovi has developed PC-based VLBI data acquisition system named K5/VSSP, and VSI-B, respectively. Additionally Metsähovi developed "real-time Tsunami", which is UDP-based network data transport software for VLBI. These technologies enabled real-time data transfer in 256Mbps observation mode. We started near-real-time UT1-observation project since April 2007. Observation data were transferred from Nordic stations to Kashima with the `Tsunami' software in real time. Then correlation processing and data analysis was carried out with software correlator developed by NICT and CALC/SOLVE software package developed by GSFC. We made a automated pipeline data processing system. Consequently UT1 observation with the minimum latency of 30 minutes became available since the end of May 2007. Now latency is further shortened to be less than 4 minutes by use of improved pipeline processing.

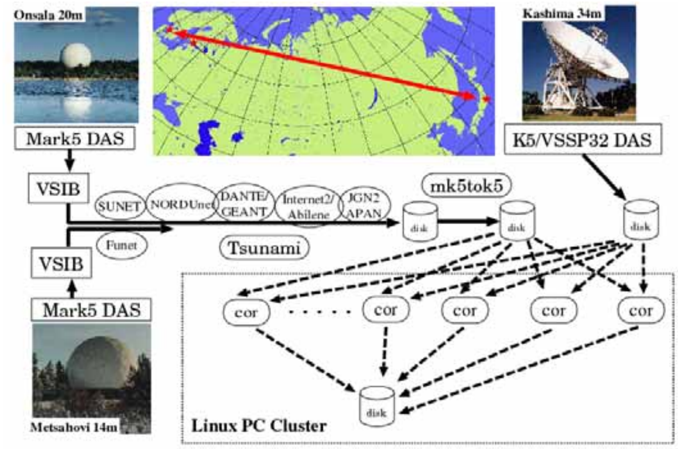

Fig.1. VLBI stations participating the Ultra-rapid UT1 measurements and a block diagram of data flow and data processing.

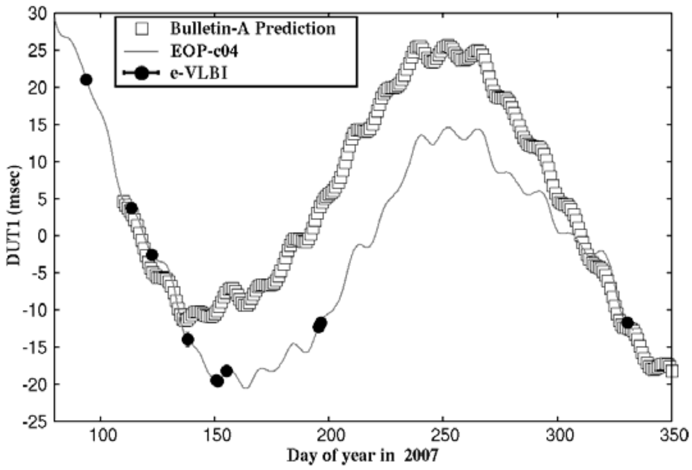

Fig.2. Comparison of UT1-UTC among EOPc04, prediction of Bulletin-A, and e-VLBI observation. Linear trend of UT1-UTC has been removed in advance. It is obvious that UT1 measured by e-VLBI observation has higher precision than prediction values.

The UT1 data measured by this project is plotted in Fig.2, where the UT1 data by e-VLBI observation is compared with prediction and rapid combined solution of bulletin-A. That plot indicates the UT1 values observed on these baselines have the accuracy of the same level with rapid combined solution. This e-VLBI project will be continues with aim of (a) confirmation of stable operability of ultra-rapid UT1 observation with e-VLBI technology, (b) improvement of observation precision with higher data rate, (c) consistency of ultra-rapid UT1 results with standard IVS results.

3. Development of K5 system

NICT has been developing a series of sampler and hard disk recording system called K5 system since

1990's. From the very beginning of the development of K5 system, it is intended to use a commercially sold PC and transfer the data through the Internet, i.e., dedicated to e-VLBI. K5 system is categorized into two series: 1) ADS series sampler equipped with a VSI-H interface and a PC-VSI recorder also equipped with a VSI-H interface; 2) VSSP series sampler not equipped with a VSI-H but directly connectable to a host PC.

K5/VSSP is a sampler developed based on this idea. K5/VSSP itself is a PCI-bus board having 4 video signal inputs and can sample each signals with a frequency of up to 16 MHz with 1 bit A/D resolution [Kondo, et al., 2003]. So we can use a PC as not only a 4-ch sampler but also a hard disk recorder, and 4 PCs can cover 16 channels which is sufficient number of channels in case of geodetic VLBI. Furthermore each PC can work as a server in e-VLBI system.

Fig.3. K5/VSSP32 16ch module.

K5/VSSP32 is a successor to the K5/VSSP, but a USB 2.0 is newly adopted as an interface with a host PC [Kondo, et al., 2006]. Maximum sampling frequency per channel is increased up to 64 MHz. As a K5/VSSP32 unit has 4 channel analog inputs, 4 units can cover 16 channels (Fig.3). By adopting a USB interface, we can realize a real-time data transfer during an observation. Now K5/VSSP32 is used for ultra rapid UT1 measurement regularly and also widely used in Japan.

Fig.4. High-speed sampler ADS3000+

ADS1000 is the first sampler equipped with a VSI-H interface. It has one signal input and can sample signals with 1024 MHz sampling frequency with 2 bit A/D resolution [Nakajima, et al., 2001]. It is used in the VERA project and KVN project. ADS2000 is a 16-ch sampler dedicated to a geodetic VLBI observation and was developed to substitute for DFC2000 that is an aging sampler for tape recording system [Koyama, et al., 2006].

ADS3000 is a successor to the ADS1000 but it is equipped with two VSI-H ports and is greatly improved in the performance [Takeuchi, et al., 2006]. By use of a high-performance FPGA it is possible to output in a variety of modes with a data rate of up to 4 Gbps . Furthermore, FPGA code is rewritable so that it can be used for multiple applications such as digital baseband converter (DBBC) for multi-channel geodetic VLBI, software demodulator for spacecraft downlink signal in spacecraft VLBI or satellite communications, or spectrometer for broadband astronomical observations. Now improved version of ADS3000 named ADS3000+ is under the development (Fig. 4). A sampler device is replaced by a higher performance one (4096 MHz sampling is available) and more powerful FPGA devices are adopted to utilize a digital base band converter (DBBC).

K5/VSI is a VSI interface PCI-bus card developed by NICT [Kimura, et al., 2003]. A PC equipped with this card can receive data stream output not only from ADS series sampler but also from other VSI-H instruments. Now we can record the data stream with a speed of up to 2 Gbps for 16 hours using sixteen 1TB hard disks [Kimura, 2007].

Table 1 summarizes specifications of K5 samplers (VSSP and ADS series).

Table 1. Specifications of K5 samplers (VSSP and ADS series)

	VSSP	VSSP32	ADS1000	ADS2000	ADS3000	ADS3000+
Ref. Signal	10MHz 1PPS	10MHz/5MHz 1PPS	10MHz 1PPS	10MHz 1PPS	10MHz 1PPS	10MHz 1PPS
# of Inputs	4	4	1	16	1	2, 4
A/D bits	1,2,4,8	1,2,4,8	1,2	2	8	8
Max Sampling Freq (MHz)	16	64	1024	64	2048	4096
Interface	PCI-bus	USB2.0	VSI-H	VSI-H	VSI-H x 2	VSI-H x 4
Function		Digital LPF		PCAL detection		DBBC

4. Development of software correlator

NICT has developed a K5 software correlator for processing K5/VSSP and K5/VSSP32 data. The processing speed of K5 software correlator has continued to increase with the progress of PC performance. Throughput of the K5 software correlator for a geodetic use is now approaching 32 Mbps for 32-lag correlation and 64 Mbps for 16-lag with a single CPU.

We have also developed an FX-type software correlator, which is specialized for processing speed to process gigabit VLBI system data, mostly for an astronomical use [Kimura, et al., 2003]. In order to bring out the maximum performance, various kinds of optimizations, such as an effective use of multi-processors and utilization of SIMD (Single Instruction Multiple Data) technology for parallel processing, are applied into the software. An assembler language program is also used partially to improve the performance. Benchmark test of the software correlator that runs on an Xserve G5 equipped with dual 2GHz G5 processors showed the throughput of about 500 Msps (sample per second) at 1024 FFT points, which corresponds to the processing speed of 1 Gbps for 2 bit sampling data. Now this FX-type software correlator can process 512Msps x 2bit sampling data of 5 stations (i.e., 10 baselines) in real-time by use of 5 PCs equipped with dual Intel Xeon X5355 CPUs.

In addition to the development of the software correlator, efforts have been made to realize distributed processing by using multiple PCs for a geodetic VLBI data processing. Initially a screen saver program to download the data files from a server and perform the software correlation was developed on the Microsoft Windows operating systems [Takeuchi, et al., 2004]. We named this system VLBI@home which consists of a server PC and client PCs. The screen saver program runs on the client PCs. The server program run on the server PC processes the requests from the clients. Any PCs connected to the Internet could be used as the clients. Later more effective distributed processing system dedicated to near real-time processing has been realized by using a shell script.

5. VLBI2010 and related development

Current geodetic VLBI system was constructed mostly in 1980's. Gradually it becomes difficult to keep the accuracy due to increasing radio interference signals (RFI). Old and slow-slew rate antennas also make it difficult to adopt a new observation strategy such as the increase of the number of observations in a day. To overcome these situations IVS started a discussion in 2003 about the next generation geodetic VLBI system called VLBI2010, and the first report was issued in 2005. Discussion is still continued. Table 2 shows the summary of VLBI2010 at present time.

Table 2. Summary of VLBI2010

	Current	VLBI2010
Antenna Size	5 – 100 m dish	~ 12 m dish
Slew Speed	~0.3 – 3.3 deg/sec	≥ 6 deg/sec (5 deg/sec)
Sensitivity	200-15,000 SEFD	≤ 2,500 SEFD
Frequency Range	2/8	~2 – 18 (15) GHz
Polarization	RHCP	Dual Polarization
Data Rate	128, 256 Mbps	8 – 16 Gbps future 32 Gbps
Data Transfer	Ship disks, some e-transfer	e-transfer, e-VLBI, some ships

NICT has been developing a 2.4 m antenna VLBI system named CARAVAN2400 in collaboration with GSI for various R&D purposes, such as to evaluate the performance of a small antenna system as geodetic VLBI system, to test the design of antenna system in VLBI2010 [Ishii, et al., 2007]. A quad-ridge horn antenna (QRHA) (Fig.5) that covers a frequency range of 2-18 GHz has been implemented at a main focal point of CARAVAN2400 as a wide band feed since November, 2007. Wide-band RF signals received by the QRHA are filtered to S and X bands by a diplexer and fed to a VLBI backend. A fringe test was successfully carried out on December 5, 2007. Since then geodetic observations have been performed several times to evaluate the performance of small antenna system. We are now developing, also in collaboration with GSI, a 1.6m antenna system equipped with a wide band feed for the MARBLE (Multiple Antenna Radio-interferometry for Baseline Length Evaluation) project that is a project to measure a reference baseline maintained by GSI by using a VLBI technique for the calibration of surveying equipments.

Fig.5. A quad-ridge horn antenna (QRHA). It can cover 2-18 GHz.

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