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Geodetic VLBI Experiments with the K5 System

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Abstract

At Kashima Space Research Center of Communications Research Laboratory, developments of the K5 VLBI system have been continuing based on conventional PC systems to realize e-VLBI observations and data processing over the Internet. By using the prototype models of the K5 system, various geodetic VLBI experiments have been performed and the results were evaluated to investigate the performance and the function of the K5 system. In the two domestic geodetic VLBI experiments, the results from the K5 system were compared with the results from the K4 system and it was confirmed that the K5 system is performing as expected. A series of short e-VLBI sessions was performed by using the Mark 5 system at Westford station and the K5 system at Kashima station to demonstrate rapid turn around UT1-UTC estimation from international e-VLBI. Since October 2003, all IVS sessions in which Kashima 34-m station participated were recorded by the VLBA recorder as well as by the K5 system in parallel, and the K5 data files were transferred to MIT Haystack Observatory after converting the format of K5 data files to the Mark 5 data format. The data were then recorded to Mark 5 disk units for correlation processing. These procedures will become first and important steps towards the routine e-VLBI operations in the IVS sessions in the future.

1. Introduction

After the prototype models of the K5 system were developed, the K5 system is beginning to be used for various VLBI observations such as the precise orbit determination of the spacecrafts Nozomi and Geotail [1] and the demonstration of international e-VLBI observations [2]. Therefore, it is very important to ensure that there is no problem with the performance of the K5 system by comparing the results from the K5 system with the results from the conventional VLBI systems such as the K4 system. For this purpose, two domestic geodetic VLBI sessions were carried out to evaluate the performance and functions of the K5 system. The compared results from these two VLBI sessions will be presented in this report. Then, the recent activities of using K5 system in the international geodetic VLBI sessions will also be introduced.

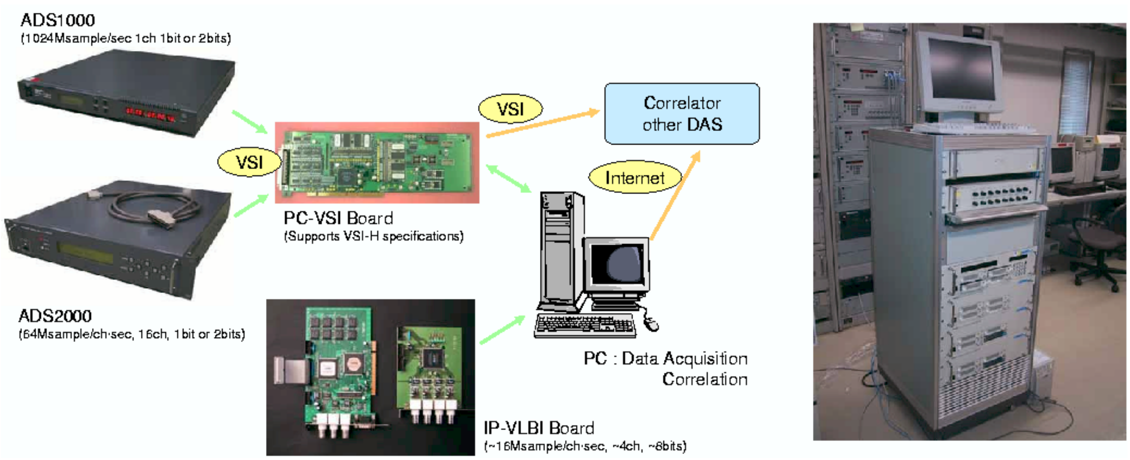

Figure 1. Concept of the entire K5 system (left) and the picture of the prototype model (right).

2. K5 System

The K5 system is designed to perform real-time and near-real-time VLBI observations and correlation processing using Internet Protocol over commonly used shared network lines. Various components are being developed to realize the target goal in various sampling modes and speeds. The entire system will cover various combination of sampling rates, number of channels, and number of sampling bits by selecting subset of the available systems shown in Figure 1. The K5 system is characterized by the use of conventional PC systems and the IP based shared network such as Internet. The data correlation can be performed by hardware correlators which support VSI-H specifications as well as by using the software correlator programs. In a similar fashion, the K4 system is characterized by the use of magnetic cassette tape recorders with rotary-heads and the dedicated network based on ATM (Asynchronous Transfer Mode).

For observations with relatively low data sampling rates, the output signal of the base-band converters are sampled with the IP-VLBI board and the sampled data are directly processed with the PC system to which the IP-VLBI board is installed. All the conventional geodetic VLBI modes of total data rate up to 512 Mbps with 16 channels can be covered. The prototype model of the K5 system (also shown in Figure 1, which is called Versatile Scientific Sampling Processor (VSSP), is a realization of the K5 system's concept by using this configuration. It consists of four UNIX PC systems. Each UNIX PC system has one IP-VLBI board. Because the IP-VLBI board supports various sampling modes, it has many possibilities to be used not only for VLBI observations but also for various other scientific researches which require precise timing information in the data. A signal distributor unit for 1 PPS and 10 MHz signals and 16-channel base-band signal variable amplifier unit are mounted in the upper part of the rack. The monitor and the keyboard on the top of the rack are connected to the four PC systems by using a four-way switch. Each PC system is equipped with four removable hard disk drives of the data capacity of 120 GBytes each. The sampled data can be transferred to the network by using TCP/IP or can be recorded to internal hard disks as ordinary data files. The maximum recording speed of 512 Mbps has been achieved with the current configuration.

To process the data sampled with the K5 system, software correlation programs are also under development. The software correlation programs receive data from K5 systems over the Internet and then calculate cross correlation functions. It can also read data files on internal hard disks after transferring the data. These capabilities allow us to transfer observed data in real-time if the connecting network is fast enough, and in near real-time if data buffering is required. Since easily re-writable software programs and general PC systems are used, the processing capacity and the function of the correlator can be easily expanded and upgraded.

3. Evaluation of K5 System in Geodetic VLBI Experiments

Two geodetic VLBI sessions were performed with domestic baselines in Japan by using K5 and K4 systems to evaluate the performance and functions of the K5 system. The first session was performed using two 11-m antennas at Kashima and Koganei from January 31 to February 1, 2003. The second session was performed using the opportunity of a domestic regular geodetic VLBI session coordinated by Geographical Survey Institute (GSI). The session, which is called JD0306, was performed for 24 hours from July 16, 2003. As a regular domestic experiment, four VLBI stations operated by GSI at Tsukuba (32-m), Shintotsukawa (3.8-m), Chichijima (10-m), and Aira (10-m) participated with the K4 systems. At Tsukuba station, K5 system was used in addition to the K4 system. By using the same observing schedule, Kashima (11-m), Tomakomai (11-m), and Gifu (11-m) stations participated in the session by using both K5 and K4 systems. In addition, Yamaguchi (32-m) station participated in the session by using K5 system only in X-band.

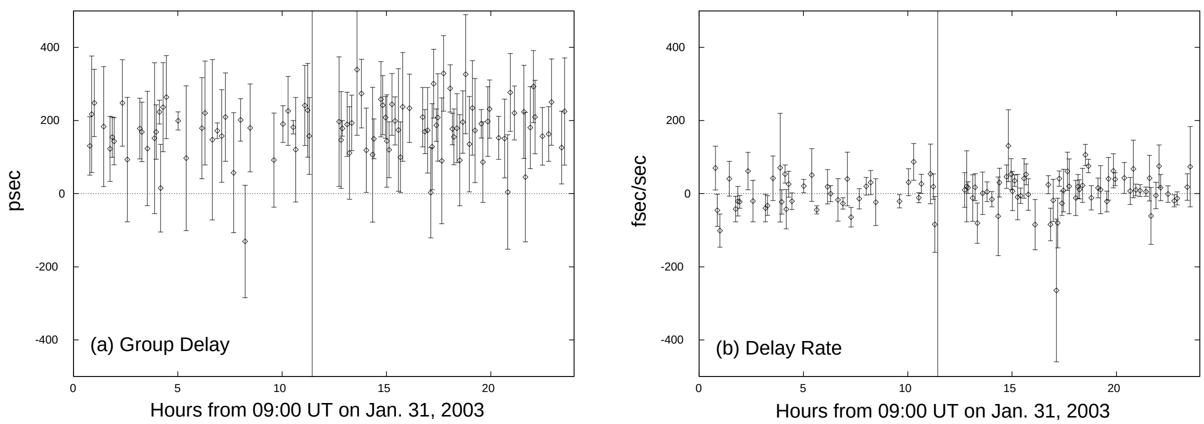

Figure 2. Difference of (a) group delay and (b) delay rate obtained from K4 and K5 systems.

In both sessions, the data files recorded with the K5 system were processed by the software correlation programs and the K4 observation tapes were processed by using the K4 hardware correlator at Kashima and Tsukuba. Both data were then analyzed by CALC and SOLVE softwares developed by Goddard Space Flight Center of National Aeronautics and Space Administration. Figure 2 shows the difference of group delay and delay rate determined by K5 and K4 systems. The constant offset seen in the group delay comparison can be absorbed as a part of the clock difference estimated through the data analysis processing and therefore it does not cause any problem in the data analysis. The RMS of the difference is calculated as 72.7 psec for group delay and 118 fsec/sec for delay rate. Table 1 compares the baseline lengths estimated from the data obtained with K5 and K4 systems. Since the K5 system at Kashima and Gifu stations stopped

Table 1. Comparison of baseline lengths estimated from the data obtained with K4 and K5 systems.

Exp.	Baseline	System	No. of valid data	Baseline Length (mm)	RMS Residual Delay (psec)	RMS Residual Rate (fsec/sec)
1	Kashima-Koganei	K4	112	109099657.0 ± 6.7	76	136
		K5	159	109099641.2 ± 3.2	33	92
2	Tsukuba-Kashima	K4	176	53811894.9 ± 2.1	53	158
		K5	130	53811891.6 ± 3.1	81	121
	Tsukuba-Gifu	K4	184	311067474.0 ± 2.9	98	189
		K5	55	311067483.3 ± 4.0	58	136
	Tsukuba-Tomakomai	K4	124	740526116.3 ± 4.4	103	165
		K5	169	740526119.4 ± 5.1	103	146
	Kashima-Gifu	K4	174	358799168.6 ± 2.8	72	191
		K5	48	358799174.7 ± 4.5	92	144
	Kashima-Tomakomai	K4	171	749810979.9 ± 4.4	115	125
		K5	108	749810985.5 ± 5.5	106	143
	Gifu-Tomakomai	K4	154	902668931.2 ± 4.8	135	125
		K5	49	902668930.6 ± 6.1	116	138

recording for about six hours and 12 hours respectively during the observations, and the number of valid data for Tsukuba-Kashima and Tsukuba-Gifu baselines are fewer than the data from the K4 system. From these comparisons, it can be concluded that the estimated baseline lengths are consistent with each other within 2 times the estimated uncertainties. In addition, the comparison of the RMS residuals of group delay and delay rate suggests the performance of the K5 system is comparable with the K4 system.

4. International Geodetic VLBI Experiments

In 2003, a series of test e-VLBI sessions were performed with the Kashima-Westford baseline. The 34-m antenna VLBI station at Kashima and the 18-m antenna station at Westford were used for the observations. At the Kashima station, the K5 system was used to record the observed data. At the Westford station, the Mark 5 system developed by Haystack Observatory was used to record the observed data. The observed data were recorded to internal hard disks at each site and transferred to Kashima and Haystack Observatory after the observations by using FTP. For this purpose, a software program was used to extract the data from the Mark 5. At Haystack Observatory, file format of the K5 data files was converted and recorded to the Mark 5 system. After the conversion, data recorded at Kashima and at Westford were processed for cross correlation processing using the Mark IV correlator at Haystack Observatory. At Kashima, the Mark 5 data files were converted to K5 file format and then correlation processing was done by using the software correlation programs. The observations were performed with 14 channels (8 for X-band and 6 for S-band) and 2 MHz for each channel.

After the data processing, CALC and SOLVE software were used to perform data analysis. In the estimation process, positions of both Kashima and Westford stations were fixed to the ITRF2000 reference frame and UT1-UTC was estimated along with the clock offset, its rate, and the atmospheric zenith delay. From the 2-hour session performed on March 25, 2003, UT1-UTC was estimated with uncertainty of 23.9 microseconds, which is comparable to the results from intensive sessions. From the 2-hour session performed on June 27, 2003, the UT1-UTC was estimated within 21 hours and 20 minutes after the last observation in the session finished. For this session, file transfer speed reached 107 Mbps in the direction from Kashima to Haystack Observatory. The opposite direction was not as fast, but the speed was about 45 Mbps. Thus the rapid estimation of the EOP in less than one day was successfully demonstrated by the international e-VLBI observations and data analysis.

Since October 2003, four IVS VLBI sessions were performed including the Kashima 34-m antenna station. The K5 system was used to record observed data along with the VLBA data recorder. The data recorded with the K5 system were transferred to Haystack Observatory using the high speed research network. The K5 data files were converted to the Mark 5 file format either at Kashima before the file transfer or at Haystack Observatory after the file transfer. Then the data were recorded to the Mark 5 disk units and shipped to correlator sites. These are the first but important trials to introduce e-VLBI in the routine sessions coordinated by IVS.

5. Conclusions

The results from two geodetic VLBI experiments between K4 and K5 VLBI systems were compared to ensure that the K5 VLBI system has expected capability and performance similar or better than the K4 VLBI system. The results from two different systems are consistent with each other considering the estimated error. From these comparisons, it can be concluded that there is no problem in using the K5 VLBI system for precise VLBI observations. By using K5 system at Kashima station and Mark 5 system at Westford station, fast turn around UT1-UTC estimation from e-VLBI within a day has been successfully demonstrated. We expect we can further shorten the turn-around time by upgrading the network and using distributed software correlator system. Since October 2004, all IVS sessions in which Kashima 34-m station participated were recorded by the K5 system and we are planning to extend the e-VLBI operation to other IVS observing stations.

6. Acknowledgements

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