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e-VLBI Developments with the K5 VLBI System

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Abstract

The K5 VLBI system has been developed at the Kashima Space Research Center of the National Institute of Information and Communications Technology (NICT). The concept of the K5 VLBI system is to realize real-time VLBI observations and correlation processing under the various observing modes by combining multiple components in a flexible manner. The system is also intended to be VSI-H compliant by using the VSI-H PCI interface card and VSI-E compliant by developing a set of software programs that work with the vtp (VLBI Transfer Protocol) libraries developed at Haystack Observatory. The current status of the K5 VLBI system's developments and the recent achievements for e-VLBI by using the K5 VLBI system will be reported.

1. Introduction

Recent research and developments in network technology have resulted in an environment in which the network data transmission rate far exceeds the data recording rate of magnetic tape recorders (typically 1024Mbps) and recent disk based VLBI recording systems. Therefore, a significant improvement in the sensitivity of VLBI observations can be expected if real-time correlation processing of observation data can be performed without the data recording procedure at observing sites. In addition, with the near-real-time processing of VLBI observation data enabled by e-VLBI, a high-precision estimation of the irregular variations of Earth orientation parameters becomes theoretically possible, which in turn can lead to improved precision in tracking deep-space probes and more precise determination of the satellite orbital information required for high-precision GPS measurements. These developments are expected to make a significant overall contribution to the fields of space exploration and geodesy.

Nevertheless, technical problems remain in the high-speed transmission of massive volumes of data over the Internet. Some of these problems form interesting themes for research and developments in network technology, with topics including maximizing use of available data transmission capacity in the presence of other types of traffic or effective congestion control under the situation of significant network transmission delay. Accordingly, numerous researchers are currently focusing concerted efforts on these and similar challenges.

In the past, the Tokyo Metropolitan Wide Area Crustal Deformation Monitoring Project (also known as the Keystone Project, or KSP) launched by the Communications Research Laboratory (CRL, now NICT) represented the first efforts to introduce the e-VLBI concept into the daily VLBI operations. System development for the project had as its goal the high-precision, high-frequency measurements of the relative positions of four VLBI stations, and was structured to override the existing framework of VLBI observation systems at several points [3]. One such innovation involved the realization of real-time VLBI observation data processing for the four-station, six-baseline array via an ATM (Asynchronous Transfer Mode) network. This system, developed under the auspices of a collaboration between CRL and NTT Communications, Inc., dramatically reduced the time required for data processing relative to existing systems, which relied on magnetic tape recording. Further, this was the first system of its kind to be completely automated from observation to data processing and analysis with the results of the analysis of nearly non-stop VLBI observations automatically available to the public on the Internet [1]. The development of this system proved that e-VLBI technology could enable near-real-time data processing with virtually no delay between observation and processing.

However, this observation and processing system was tailored to an ATM network. As such, the system could not be used to connect multiple VLBI stations throughout the world since it was not feasible to construct an international dedicated ATM network just for e-VLBI. To increase the versatility of this system, the development of the K5 observation and processing system was begun in 2000, eventually resolving earlier problems by enabling data transmission via IP (Internet Protocol), under Internet network conditions involving the presence of other types of traffic.

2. Developments of the K5 System

The K5 VLBI system is designed to perform real-time or near-real-time VLBI observations and correlation processing using IP 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 combinations of sampling rates, number of channels, and number of sampling bits. All of the conventional geodetic VLBI observation modes will be supported as well as other applications like single-dish spectroscopic measurements or pulsar timing observations. Table 1 shows comparisons of the K3, K4 and K5 systems in various aspects to identify the characteristics of the K5 system. As shown in Table 1, the K5 system is characterized by the use of a disk based recording method and by the use of the IP protocol for e-VLBI. The data correlation processing is performed by using software correlator programs running on multiple PC systems in the K5 system. Similarly, the K4 system can be characterized by the use of rotary-head, cassette type magnetic tape recorders, and the K3 system can be characterized by the use of open-reel magnetic tape recorders.

In contrast to the real-time correlation processing unit developed for the KSP, which realized high-speed digital data processing through the use of the FPGA, a software correlator has been developed for the K5 system to perform distributed processing using a PC running on a versatile operating system. While a hardware correlator lacks flexibility due to the extended development time required, a software correlator may be modified easily to add new functions or to revise processing modes. In addition, development is also underway for software required to enable distributed processing using available computer resources (consisting of multiple CPUs) to the maximum extent, in order to provide the needed processing capacity for data collected at numerous VLBI stations in the context of large-scale VLBI experiments.

The concept of the K5 system is shown in Figure 1. ADS1000, ADS2000, and ADS3000 are high speed A/D samplers. Output digital signals from these A/D samplers are interfaced to the PCI bus of the PC by using the PC-VSI board according to the VSI-H (VLBI Standard Interface Hardware specifications) compliant signaling. Whereas the ADS1000 is designed as a single channel high speed sampler unit, the ADS2000 is designed for geodetic VLBI observations by supporting

Table 1. Comparisons of the K3, K4, and K5 systems.

	K3	K4	K5
Data Recorders	Magnetic Tapes Longitudinal Recorders	Magnetic Tapes Rotary Head Recorders	Hard Disks
e-VLBI	Telephone Line	ATM	IP
Correlators	Hardware	Hardware	Software
Years in use	1983-	1990-	2002-
Systems	M96 Recorder, K3 Formatter, K3 VC, K3 Correlator	DIR-1000, -L -M, DFC1100, DFC2100, K4 VC (Type-1, 2), TDS784, ADS1000, GBR1000, GBR2000D, K4 Correlator, KSP Correlators, GICO, GICO2	K5/VSSP, K5/VSSP32, K5/VSI, ADS1000, ADS2000, ADS3000, Software Correlatos (cor, fx_cor, GICO3)

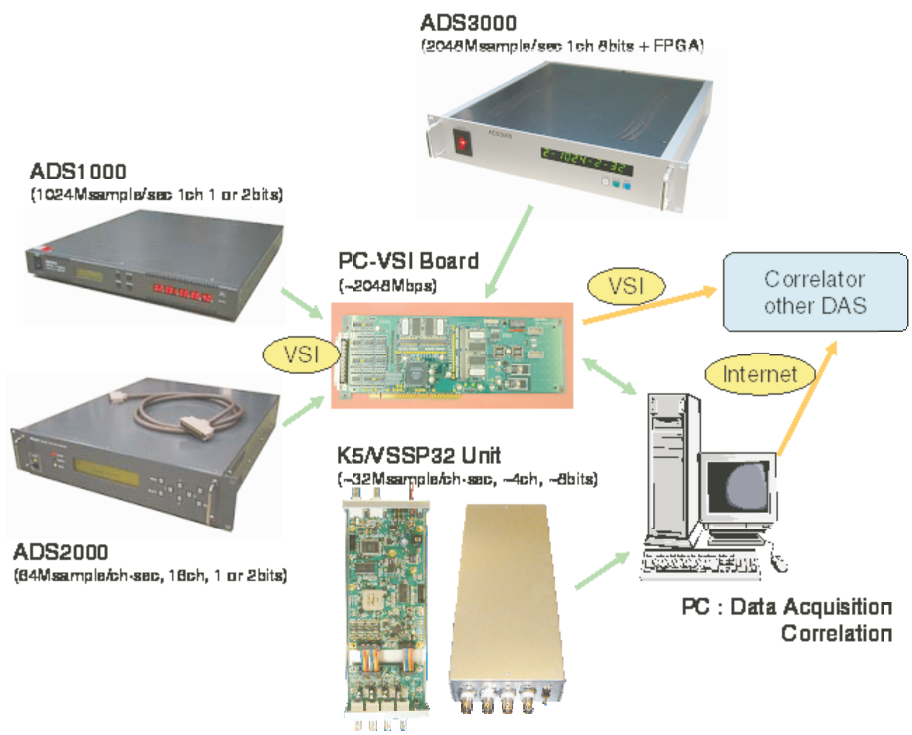

Figure 1. Concept of the entire K5 system.

16 channels with sampling rates up to 32Msps for each channel. The ADS3000 A/D sampler unit is currently under development and it will support various observing modes by using FPGA (Field Programmable Gate Array) and a 4Gsps high speed A/D sampler chip. The prototype unit of the ADS3000 has been completed and the first fringe was detected between the 34-m and 11-m stations at Kashima using single channel observations with 2048Msps, 2bits-per-sample sampling mode. When relatively low sampling rates are required, PC systems with the IP-VLBI units are

used as shown at the bottom of Figure 1. Originally, specially designed PCI boards called IP-VLBI boards were used in the K5/VSSP system. The boards are installed on the PCI expansion bus slots to support 4 input channels sampling at up to 16Msps. Recently, the external K5/VSSP32 units have been developed. The K5/VSSP32 units are connected with the PC system by using USB 2.0 interface cables. The new units support 32Msps and 64Msps sampling speeds which were not supported by the PCI type IP-VLBI boards. By using four units of the K5/VSSP32, 16 channel geodetic VLBI observations can be performed. VSSP is an acronym for Versatile Scientific Sampling Processor. This name is used because the system is designed to be used for general scientific measurements. The system has the capability to sample analog data streams by using the external frequency standard signal and the precise information of the sampled timing. The system is also used to process the sampled data. For geodetic VLBI observations, a software correlation program runs on the K5/VSSP system. Therefore, it can be said that the functions of the formatter, the data recorder, and the correlator are combined into a single system. It consists of four UNIX PC systems. In Table 2, the characteristics of these A/D sampling components developed for the K5 system are shown.

Table 2. Comparisons of A/D sampling systems in the K5 system.

	K5/VSSP	K5/VSSP32	ADS1000	ADS2000	ADS3000
Sampling Speed	40, 100, 200, 500kHz, 1, 2, 4, 8, 16MHz	40, 100, 200, 500kHz, 1, 2, 4, 8, 16, 32, 64MHz	1024MHz	64MHz	2048Msps
Sampling Bits	1, 2, 4, 8	1, 2, 4, 8	1, 2	1, 2	6
No. Channels	1, 4, 16 (with 4PCs)	1, 4, 16 (with 4PCs)	1	16	Programmable with FPGA
Max. Data Rate	512Mbps (with 4PCs)	2048Mbps (with 4PCs)	2048Mbps	2048Mbps	4096Mbps

3. e-VLBI Data Transfer Using VSI-E

By using the developed K5 system, we have started efforts to transfer the observed data over the network using the VSI-E protocol. VSI-E is under discussion to standardize the protocol of massive real-time data transfer for e-VLBI [2]. Based on the current draft proposal of the VSI-E, vtp (VLBI Transport Protocol) libraries have been developed by David Lapsley and his colleagues at Haystack Observatory. The library interfaces data stream from the transmitting sites to the receiving sites over the Internet network using either TCP/IP or UDP/IP. An interface program for the K5 data stream at the transmitting site has been developed by us and the program was used with the vtp libraries. By using these programs, a file format conversion demonstration was performed in July 2005 as shown in Figure 2. Recently, we are continuing our efforts to use these programs for real-time correlation by using the Mark IV correlator at the Haystack Observatory after converting the K5 format data stream at the transmitting site and sending the converted data stream over the network using the VSI-E protocol as shown in Figure 2. In the next step, we are planning to develop an interface for the receiving side to be converted into the K5 data stream format. When the program is completed, it will become possible to correlate the transmitted data with the K5 software correlator in real-time by using the data stream signals transmitted using the VSI-E protocol.

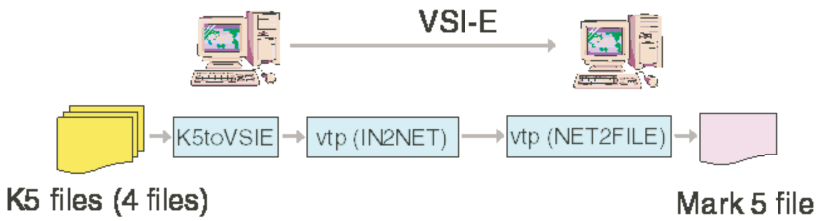

Figure 2. File format conversion by using VSI-E.

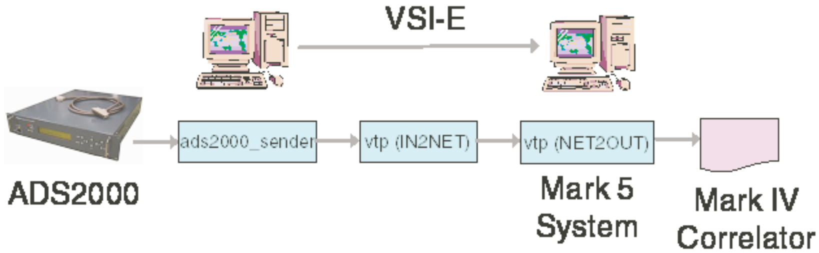

Figure 3. Real-time data transfer by using VSI-E.

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References

[1] Koyama, Y., N. Kurihara, T. Kondo, M. Sekido, Y. Takahashi, H. Kiuchi, and K. Heki, Automated geodetic very long baseline interferometry observation and data analysis system, Earth Planets Space, **50**, pp. 709-722, 1998.

[2] Draft Proposal for VSI-E - Rev 2.7, available at ftp://web.haystack.mit.edu/pub/e-vlbi/, Jan. 2004.

[3] Yoshino, T., Overview of the Key Stone Project, Special Issue of the J. Comm. Res. Lab., **46**, pp.3-6, 1999.