Mamoru Sekido et al.: Development of an e-VLBI Data Transport Software Suite with VDIF, IVS 2010 General Meeting Proceedings, p.410–414
http://ivscc.gsfc.nasa.gov/publications/gm2010/sekido.pdf

Development of an e-VLBI Data Transport Software Suite with VDIF

Mamoru Sekido [1], Kazuhiro Takefuji [1], Moritaka Kimura [1], Thomas Hobiger [1], Kensuke Kokado [2], Kentarou Nozawa [3], Shinobu Kurihara [2], Takuya Shinno [4], Fujinobu Takahashi [4]

1) *National Institute of Information and Communications Technology*

2) *Geospatial Information Authority of Japan*

3) *Advanced Engineering Services Co.,Ltd.*

4) *Electronic and Computer Engeneering. Faculty of Engneering, Yokohama National University*

Contact author: Mamoru Sekido, e-mail: `sekido@nict.go.jp`

Abstract

We have developed a software library (KVTP-lib) for VLBI data transmission over the network with the VDIF (VLBI Data Interchange Format), which is the newly proposed standard VLBI data format designed for electronic data transfer over the network. The software package keeps the application layer (VDIF frame) and the transmission layer separate, so that each layer can be developed efficiently. The real-time VLBI data transmission tool 'sudp-send' is an application tool based on the KVTP-lib library. 'sudp-send' captures the VLBI data stream from the VSI-H interface with the K5/VSI PC-board and writes the data to file in standard Linux file format or transmits it to the network using the 'simple-UDP' (SUDP) protocol. Another tool, 'sudp-recv', receives the data stream from the network and writes the data to file in a specific VLBI format (K5/VSSP, VDIF, or Mark 5B). This software system has been implemented on the Wettzell–Tsukuba baseline; evaluation before operational employment is under way.

1. Introduction and Motivations

Progress in computer technology and high-speed networks have changed VLBI to so-called e-VLBI, which brings a number of advantages to the VLBI community. Remarkable benefits are not only quick transportation of VLBI data from observatory to data processing center via high-speed networks, but also the flexibility of data processing with software on off-the-shelf computers. One of the changes brought by e-VLBI is the software correlator, which is now being used in regular operation in place of traditional hardware correlators. Its advantages include easy maintenance and low cost for upgrading.

Another important benefit of e-VLBI is the relative ease of achieving compatibility between VLBI hardware developed by several leading institutes. The major VLBI recording and processing systems are the Mark III/IV/5 system (e.g., [1]) developed by MIT Haystack Observatory and NRAO in USA, the S2/LBA system (e.g., [2]) developed by Canadian and Australian institutes, and the K3/4/5 system (e.g., [3]) developed by NICT and NAOJ. Data compatibility and conversion issues have been drastically reduced because of the flexibility of the software-based recording system and data processing of e-VLBI.

The need for a standard data format for VLBI was discussed at the 7th International e-VLBI Workshop held in Shanghai in 2008. The VLBI Data Interchange Format (VDIF) [4] was ratified at the next international e-VLBI workshop held in Madrid in 2009. The VDIF is suitably designed for network data transmission. We anticipate that VLBI data will be exchanged in VDIF form over the network and that differences of data interfaces and formats will be absorbed at either end (sender or receiver) of the data stream. For instance, Mark 5 data may be transferred in VDIF format over the network and will be saved or processed in K5 data format at the receiving end. Based on this notion, we have developed a software library (KVTP-lib) for data handling in the standard C++ language. This software package is designed as an object-oriented class library with an emphasis on separating the transmission and application layers. Details of the KVTP-lib will be discussed in Section 3. The software tools 'sudp-send' and 'sudp-recv' have been developed as application software with the KVTP-lib for capturing VSI-H data of a Mark 5 DAS, transferring it over the network, and saving it in K5/VSSP32 format. Some results of evaluating these tools with the Intensive UT1 measurement sessions are discussed in Section 4.

2. Brief Introduction of VLBI Data Interchange Format (VDIF)

The VDIF [4, 5], which is the new standard VLBI data format designed for exchanging data over computer-based media, has a frame structure with the minimum unit composed of a 32-byte header part and a flexible-length data part. Each frame is supposed to be conveyed via packets of network protocol.

The header contains information in order to uniquely identify the epoch of the data samples. Thus it is designed to be tolerant of missing or duplicate frames. The length of the data part is an adjustable parameter; thus the capacity ratio of header part to data part can be reduced when writing a file to recording media. The VDIF is designed to be independent of the lower level transport protocol. This is an important aspect of VDIF usage. Examples of VDIF are indicated in Figure 1. Please refer to VDIF specification [5] for more detail.

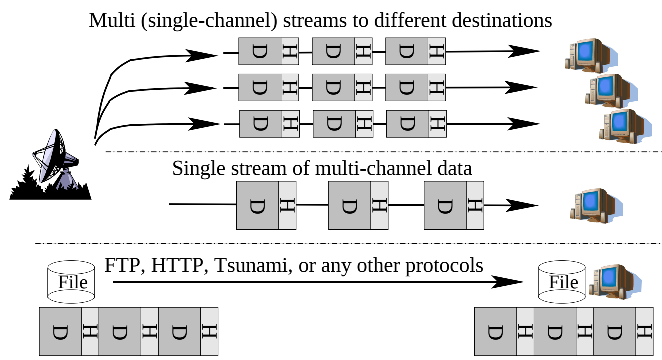

Figure 1. Examples of VDIF usage. 'H' and 'D' mean header and data parts, respectively. Data transport from data source to destination can be performed flexibly by real-time multiple single-channel streams, a single multiple-channel stream, or off-line using recording media.

3. VDIF/SUDP and C++ Class Library KVTP-lib

3.1. VDIF/SUDP

We have developed a software suite for VLBI data transport as an implementation of the VDIF. Lossless VLBI data transport via file on recording media or via TCP/IP over the network are included in the scope of VDIF; however, TCP/IP is not suitable for high data-rate transmission over long distance. Alternatively, we have introduced a simple transmission protocol, which we named SUDP, on top of the UDP/IP protocol stack. The format of the SUDP header of eight bytes size is indicated in the left panel of Figure 2. The idea of a sequential number has been used

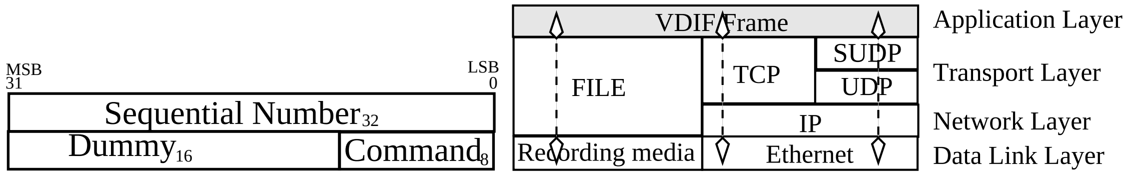

Figure 2. The left panel shows the header format of the simple-UDP (SUDP) protocol. 'Sequential number' is incremented for every packet. 'Command' may be used for 'test packet' or other functions for multi-streaming. The right panel shows the protocol stack model for VDIF and SUDP implemented in the KVTP-lib package.

in real-time VLBI experiments by JIVE/EVN. This header format was originally proposed by R. Hughes-Jones at the 8th International e-VLBI Workshop in 2009. The SUDP header belongs to the transport layer for monitoring the transmission rate, loss, and duplication of packets. Thus it is attached at the sender and stripped at the receiver. The SUDP does not include re-transmission mechanisms for lost packets. Since real-time VLBI data transfer is used and available only when the network has sufficient capacity for the VLBI observation data rate, this simple mechanism works fine for up to 512 Mbps when the network capacity is more than 600 Mbps. If a standard MTU (Maximum Transmission Unit) size of 1500 bytes and a packet size of 1464 bytes is used, the overhead cost including UDP/IP, SUDP, and VDIF header is 5.2%. For instance, a network capacity of 269.2 Mbps is needed for a data rate of 256 Mbps and a 538.5 Mbps capacity for a 512 Mbps rate. In our experience with international data transfers between European stations (Onsala, Metsähovi, Wettzell, and JIVE) and Japanese stations (Kashima and Tsukuba), sufficient network capacity was always available courtesy of the research networks (JGN2plus, SINET3, Internet2, and GÉANT3) between these stations.

3.2. C++ Class Library KVTP-lib for Real-time Data Transmission/Conversion

The class library KVTP-lib (VTP library of Kashima) has been developed for a flexible coding of data conversion/transmission tools. It has been coded in C++ adhering to the object-oriented design features of 'Encapsulation', 'Abstraction', 'Inheritance', and 'Polymorphism'. 'Abstraction' and 'Polymorphism' are techniques for reducing duplicated coding and providing common interfaces to the modules. Since any VLBI data formats (e.g., Mark 5B, K5, LBA) have essentially the same frame structure with repeating header and data parts, they are suitable for object-oriented coding via classes inherited from the same common class. By using these software features common interface functions are defined, and it is easy to switch between these different VLBI data formats. In the same way, data transport classes of TCP/IP, SUDP/UDP/IP, and FILE are easily exchanged using this library. The KVTP-lib uses a partly modified version of 'vtp-1.0.H' [6], which is a C++ class library originally developed by D. Lapsley at MIT Haystack Observatory. The application software 'sudp-send' and 'sudp-recv' have been developed for real-time VLBI data transfer over intercontinental baselines using KVTP-lib. 'sudp-send' captures the VLBI data stream from a VSI-H interface with a K5/VSI device and sends it to the network with VDIF/SUDP. 'sudp-recv' receives the data stream of VDIF/SUDP from the network and saves it in files in K5/VSSP32, Mark 5B, or VDIF format. Figure 3 gives an overview of the usage of KVTP-lib applications.

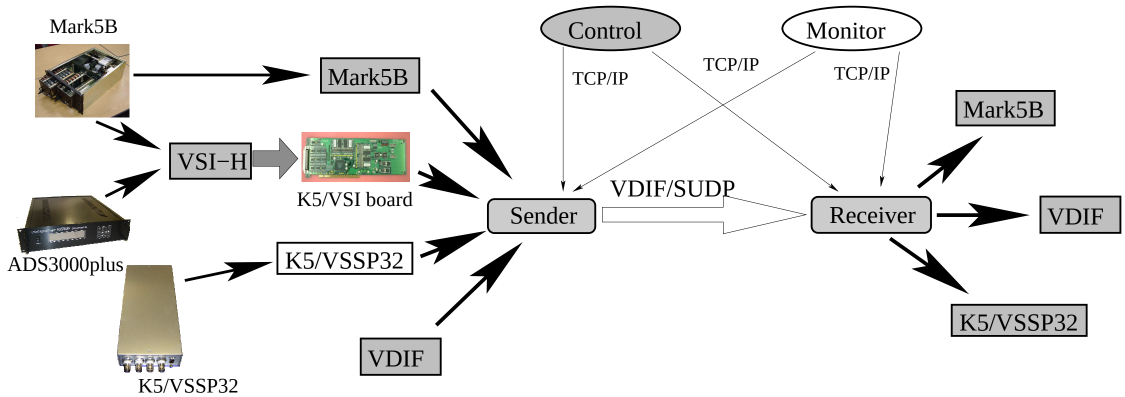

Figure 3. Overview of data transport tools 'sudp-send' and 'sudp-recv' based on the C++ class library KVTP-lib. The functions painted in gray are ready for use, whereas the ones in white are not yet implemented.

4. Application to Rapid UT1 Measurement

The real-time data transmission/conversion tools are being tested in the INT2 experiments on the Wettzell–Tsukuba baseline for rapid UT1 measurement. A Mark 5B DAS system with a VSI-H interface is continuously connected to a K5/VSI board of the server PC located at Wettzell station (Germany). During the VLBI observation, the VSI-H data stream of 16 channels at a total data rate of 256 Mbps is continuously transmitted to Tsukuba station (Japan) in VDIF format over the network in real-time. The receiver software at Tsukuba station captures the VDIF data stream from the network and saves it to four data files in K5/VSSP32 format on the fly.

Table 1. Comparison between online and offline data transport of Intensive-2 (INT2) experiments on the Wettzell—Tsukuba baseline. 'Online' (On) means real-time data transmission, and 'Offline' (Off) means conventional sequence of local recording, offline transmission with Tsunami-UDP, and format conversion from Mark IV to K5/VSSP32.

Exp. Code	**Avg. SNR_{on}/SNR_{off}** X-band	S-band	**Residual** On/Off (ps)
K10093	1.00	1.00	0.99
K10094	1.02	1.02	1.08
K10100	1.03	1.02	1.00
K10101	0.95	0.94	0.90
K10107	1.03	1.02	1.34
K10108	0.98	0.97	1.03
K10114	1.01	1.02	1.27
K10115	0.93	0.93	0.97
K10122	0.98	0.98	0.72

Comparisons between the online data transmission and the conventional scheme, where locally recorded data in Mark IV format are transferred offline, have been performed using one month of Intensive-2 experiments. The comparison results of average SNR and residuals of the UT1 analysis by CALC/SOLVE are listed in Table 1. Online transmission does not show significant differences to transmission offline. In the online case, several seconds of longer recording duration is used at the receiver side of the transmission for safety reasons. This may be the reason for some better SNR and residual values than the offline case.

5. Summary and Prospects

The software suite of C++ class library ‘KVTP-lib’ has been developed as an implementation of VDIF. A simple-UDP protocol was introduced for real-time data transmission. The VLBI data formats of K5/VSSP32, Mark 5B, and VDIF are supported at present. Since the KVTP-lib is based on an object-oriented class design, it is useful for creating application software tools for data transmission and conversion. We have written tools for K5/VSI data capture, for real-time data transmission in VDIF/SUDP, and for writing K5/VSSP32 data for the rapid UT1 measurement on the Wettzell–Tsukuba baseline.

The SUDP protocol is our own version of VTP. An international standardization of VTP is currently under discussion. Even if a new protocol is defined as standard, it can be implemented in the KVTP-lib via small modifications. The source code package of KVTP-lib is available on the Web [1] under the GPL license.

6. Acknowledgments

The authors thank Gerhard Kronschnabl for supporting our project by providing the Mark-5-VSI environment at Wettzell station. We appreciate Dan Smythe for kindly providing Mark 5/VSI board information. Finally we express special thanks to David Lapsley for his vtp-1.0.H software, which was the first proposal of a VLBI data transport protocol. His C++ class library was quite educative and useful for KVTP-lib. The current version of KVTP-lib works with our modified version vtp-1.0Hm.

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