NICT VLBI Analysis Center Report for 2017-2018

Mamoru Sekido [1]

Abstract VLBI Analysis activity of NICT is targeting for development and application of broadband VLBI for precise frequency comparison. Pair of small diameter broadband VLBI stations and high sensitivity antenna has been jointly used to derive broadband group delay between small antenna pair by using closure delay relation ('Node-Hub' style VLBI). This Node-Hub style VLBI has been verified in domestic experiments for frequency comparison between NMIJ and NICT. Then one of the small antennae was exported to Medicina station in Italy in 2018, and VLBI experiments for optical clock comparison has started.

1 General Information

Space-Time Standards Laboratory (STSL) of National Instate of Information and Communications Technology (NICT) has been conducting broadband VLBI system development for application to intercontinental precise frequency comparison. VLBI group of NICT is working at the Kashima Space Technology Center, where two radio telescopes: Kashima 34m and Kashima 11m, are located. Broadband VLBI system named GALA-V[1], which has similar broad observation frequency range (3.2 GHz - 14 GHz) with VGOS specification[2]. Unique features in our data acquisition system are utilizing originally developed broadband 'NINJA' feeds, and RF-Direct sampling by 16GHz sampling rate and following digital filtering. Additionally, Node-Hub style VLBI[4], which utilizes group delay observable between small antenna pair derived by using closure delay relation is a challenging approach for geodesy and frequency transfer VLBI.

This report describes activity on VLBI analysis in NICT VLBI group, focusing on the analysis for geodesy and frequency transfer with the broadband VLBI system.

NICT/ Kashima Space Technology Center

NICT Analysis Center

IVS 2017+2018 Biennial Report

2 Component Description

NICT is in charge of keeping and supplying national Japanese Standard Time (JST) and standard frequency traceable to the 'second' of the International System of Unit (SI). Current definition of the 'second' of time is made by using microwave emission from Cs atom. That is expected to be replaced by a new definition by using more accurate optical frequency emission from certain kind of atom in near future[5]. Several kinds of atoms are investigated as the candidates of the new definition. Then, accurate frequency comparison technique between different optical frequency standards is required, especially that can be used for intercontinental distances. Based on these background, VLBI application for frequency transfer is mission of VLBI group of NICT. The observation scheme of VLBI session for clock comparison is basically the same with standard VLBI session for geodesy. We have decided to use transportable small diameter telescope as a node of the frequency comparison. Because it need to be installed at a metrological institute, where optical frequency standard as the subject of comparison is operated.

Here, VGOS-like broadband VLBI system brings two benefits; 1) enhancement of signal to noise ratio (SNR) by increased number of samples, and 2) improvement in precision of group delay measurement via one order wider observation frequency range with respect to conventional VLBI system using S/X band receivers. Correlation amplitude of VLBI is proportional to geometrical mean of aperture area of two antennas. Thus, combination use of small antenna and high sensitivity antenna enables small antenna to work as node of interferometer. Due to these enhancement of SNR and delay precision transportable small VLBI station can be used as the node of frequency comparison on intercontinental baseline.

The GALA-V[1] system acquires 4 channels of 1 GHz bandwidth data. Cross correlation processing and post processing (fringe fitting) of the broadband VLBI data is made by GICO3[6] software correlator, and wideband bandwidth synthesis software ’komb’[7], respectively. Derived delay observable and auxiliary data are stored in Mk3 database system via MK3TOOLS[8]. VLBI data analysis has been made by CALC Ver.11.01 and SOLVE Ver.2014.02.21 developed by the NASA/GSFC.

3 Staff

Members who are contributing to the Analysis Center at the NICT are listed below (in alphabetical order):

- KONDO Tetsuro: Development of broadband bandwidth synthesis software ‘komb’.
- SEKIDO Mamoru: Coordinating of broadband VLBI observations and in charge of data analysis with CALC/SOLVE.
- TAKEFUJI Kazuhiro: Maintaining and operating correlation software ’GICO3’ for broadband data processing.

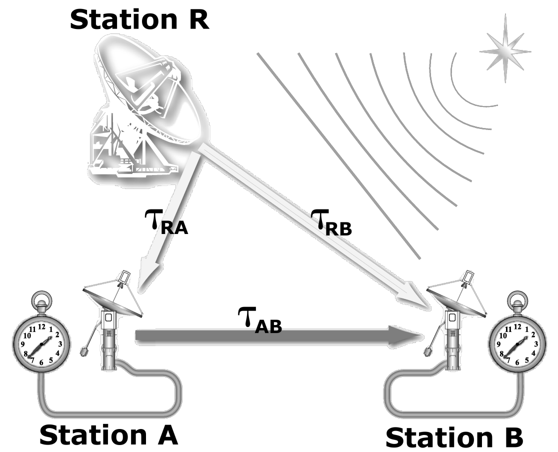

Fig. 1 The concept of the ‘Node-Hub’ style VLBI by combination use of transportable small diameter VLBI stations and high sensitivity antenna.

4 Activities during 2017-2018

4.1 Testing GALA-V system in domestic network

The concept of GALA-V project based on ‘Node-Hub’ style VLBI is displayed in Fig. 1. When observing radio source is point source, circular sum of time delay, which is arrival time difference of identical wavefront to each station, around a closed triangle baselines becomes zero. By using this closure delay relation, the delay observable (τ_{AB}) between the small diameter antenna pair (AB) is computed by linear combination of those (τ_{RA}, τ_{RB}) of the small and large diameter baselines (RA,RB). Due to time tag of the delay is defined as signal arrival epoch to **X** station of **XY** baseline, computing closure delay is given by following formula with better than one pico second accuracy on any baselines on the earth.

$$\begin{aligned}&\tau_{AB}(t_{prt})\\&=\tau_{RB}(t_{prt}-\tau_{RA}(t_{prt}))-\tau_{RA}(t_{prt}-\tau_{RA}(t_{prt}))\\&\cong\tau_{RB}(t_{prt})-\tau_{RA}(t_{prt})-\frac{d}{dt}\tau_{AB}(t_{prt})\times\tau_{RA}(t_{prt}),\end{aligned}\tag{1}$$

where t_{prt} is the reference epoch of the delay data.

Transportable broadband VLBI station of 1.6 m diameter antennas equipped with high speed data acquisition system has been installed at the National Meteorology Institute of Japan (NMIJ) in Tsukuba since

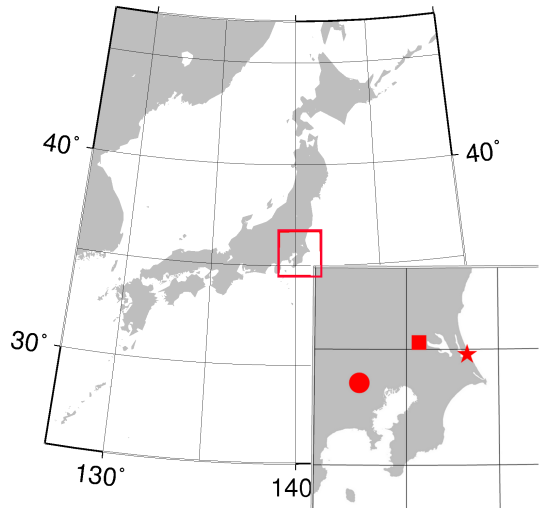

Fig. 2 Location of two small broadband VLBI station MARBLE1 (■) at NMIJ, MARBLE2 (closed circle) at NICT Headquarters and Kashima 34m antenna (★).

Table 1 Broadband VLBI Experiments conducted in 2017-2018. Abbreviation of station names are as follows: Kas34: Kashima 34m antenna, MBL1: MARBLE1 2.4m diameter antenna at NMIJ, MBL2: MARBLE2 2.4 m diameter station at NICT Koganei, OTNE: Onsala Twin Telescope North East.

Session Date	Stations	No.Scans (Used/Total)	Session Length
13-14 Jan. 2017	Kas34-MBL2	110/110	21 hours
21-23 Apr. 2017	Kas34-MBL1-MBL2	1707/1722	49.5 hours
12-13 May 2017	Kas34-MBL1-MBL2	948/1210	28 hours
09-12 Jun. 2017	Kas34-MBL1-MBL2	2237/2284	64.7 hours
03-06 Jul. 2017	Kas34-MBL1-MBL2	2120/2182	70 hours
10-14 Aug. 2017	kas34-MBL1-MBL2	Failed	77.5 hours
25-28 Aug. 2017	Kas34-MBL1-MBL2	Failed	66 hours
11-13 Nov. 2017	Kas34-MBL1-MBL2	Failed	60 hours
18-20 Dec. 2017	Kas34-MBL1-MBL2	1222/1231	40 hours
22-23 Dec. 2017	Kas34-MBL1-MBL2	998/1011	30 hours
26-27 Dec. 2017	Kas34-MBL1-MBL2	1087/1175	33 hours
03-05 Jan. 2018	Kas34-MBL1-MBL2	Failed	42 hours
12-13 Jan. 2018	Kas34-MBL1-MBL2	826/864	50 hours
18-21 Jan. 2018	Kas34-MBL1-MBL2	1431/2444	69.5 hours
31-28 Jan. 2018	Kas34-OTNE	1431/2444	17 hours
27-28 Mar. 2018	Kas34-OTNE	158/199	17 hours

2014. Another 1.5 m diameter antenna is located at NICT Headquarters in Koganei, Tokyo. These small antennas were originally designed with prime forces optics. Then antenna system of NICT and NMIJ was exchanged to 2.4m diameter Cassegrain focus optics in 2016 and 2017, respectively.

Both NMIJ and NICT are the national institutes of keeping the time series of UTC(NMIJ) and UTC(NICT), respectively. And their time data is routinely reported to BIPM (Bureau international des poids et mesures). Thus frequency comparison between UTC(NMIJ) and UTC(NICT) is possible in multiple ways other than VLBI. Hence this is a good testbed to examine the performance of our VLBI frequency link.

In March 2017, antenna system of MARBLE1 was replaced with 2.4m diameter Cassegrain focus optics. A series of test VLBI sessions conducted in 2017 are listed in Table 1. Session length is better as longer for frequency comparison. That is the reason of session length is longer than 24 hours of standard geodetic VLBI session. In the August of 2017, there were trouble of optical fiber cable break at MARBLE2. Then it was recovered by using spare fiber cable. Another trouble of instability of wideband optical RF signal transmission system occurred at MABLE1. It was recovered by replacement of optical signal transmission system from Sumitomo E18000 to FiberOptic TX:10341C/Rx:10458E.

As described above, we are testing Node-Hub style VLBI, which uses delay observable composed by linear combination based on closure delay relation. The closure delay relation is affected if radio source has structure[9]. Since its influence becomes larger as baseline becomes longer, thus it does not make significant effect in VLBI experiment of domestic short baseline ($\leq 100km$). One of the benefits of Node-Hub style VLBI is cancellation of delay variation introduced by large diameter antenna. We have confirmed the benefit of new VLBI observable approach in this baseline. Improvement of delay residual by using this technique is described in NICT analysis center report for 2015-2016[10].

4.2 Clock Comparison between UTC(NMIJ) and UTC(NICT)

We conducted a series of experiments from 18th Dec. 2017 to 3rd Jan. 2018 with about 4 days interval. Comparative evaluation of the frequency transfer performance was made between difference techniques. Data

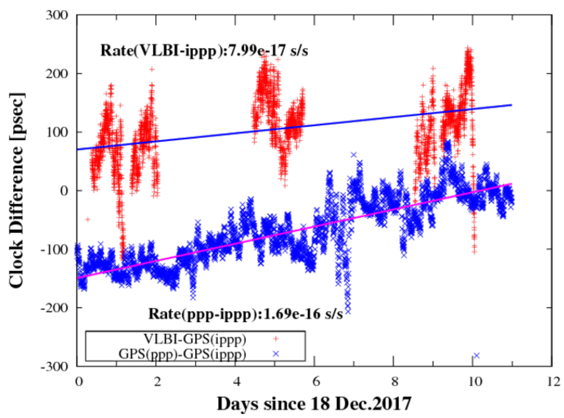

Fig. 3 Comparison of frequency techniques by double difference between VLBI-IPPP, and PPP-IPPP.

of UTC(NMIJ)-UTC(NICT) by Precise Point Positioning processing (PPP) of GPS data is available from ftp site of BIPM. In addition, thanks to courtesy of G. Petit and J. Leute of BIPM, frequency comparison by integer PPP (IPPP) processing of GPS data, which has 1^{-16} precision for frequency transfer[11], was provided for evaluation of VLBI frequency link. Double difference data of UTC(NMIJ)-UTC(NICT) for the pairs of VLBI-IPPP and PPP-IPPP are plotted in Fig. **??**. This data shows that VLBI frequency link has potential to give accurate frequency transfer better than PPP processing of GPS data. Phase ambiguity observable is potential cause of wrong delay derivation in case of GPS using carrier phase. Long term stability of VLBI data in terms of clock comparison is thought to be based on the fact that VLBI makes group delay observable instead of phase. Especially in case of our broadband VLBI, absolute delay is obtained without ambiguity.

4.3 Other activities

Space Geodesy Software C5++ : Space geodesy analysis software package "C5++" [12][1], has been developed under multi-organization collaborations. M. Sekido is taking a part of development and keeping maintenance of the software.

MK3TOOLS : Software package MK3TOOLS is a package of platform independent VLBI database read and write software originally developed by T. Hobiger. Currently T. Hobiger at University of Stuttgart in Germany and M. Sekido of NICT are jointly maintaining the package. MK3TOOLS is freely available from web at http://hg.hobiger.org/MK3TOOLS/. .

[1] http://www2.nict.go.jp/sts/stmg/www3/c5++/

5 Future Plans

optical clock comparison under collaboration among Istituto Nazionale di Ricerca Metrologica (INRiM), National Institute for Astrophysics (INAF) and NICT. Node-Hub style VLBI using closure delay relation is tested on this over 8000km baseline.

Acknowledgements

We thank Dr. Kennichi Watabe, Dr. Tomonari Suzuyama, and Dr. Kazumoto Hosaka of NMIJ for their support at NMIJ. We thank Dr. Gérard Petit and Dr. Julia Leute of BIPM for providing GPS(IPPP) solution. VLBI experiment for optical clock comparison is conducted under collaboration among INRiM, INAF, BIPM, and NICT. High speed network environment is supported by the High Speed R&D Network Testbed JGN. Network security and high speed LAN environment is supported by K. Namba and Y. Okamoto of Information System Group of NICT .

References

1. Sekido M., et al., "Broadband VLBI System GALA-V and Its Application for Geodesy and Frequency Transfer", Proceedings of 23th European VLBI for Geodesy and Astrometry Meeting, pp.5-9, 2017.
2. Petrachenko, B., et al., "Design Aspects of the VLBI2010 System", Progress Report of the VLBI2010 Committee. NASA Technical Memorandum, NASA/TM-2009-214180, June 2009.
3. Takefuji K, et al., "High-order Sampling Techniques of Aliased Signals for Very Long Baseline Interferometry", PASP 124 pp.1105-1112, `https://doi.org/10.1086/668232`, 2012.
4. Sekido, M., " 'Node - HUB' Style VLBI with Broadband System", IVS NICT-TDC News. No.37, pp.22-25,

http://www2.nict.go.jp/sts/stmg/ivstdc/news_37/pctdc_news37.pdf, 2017.

5. Riehle F., “Towards a Re-definition of the Second Based on Optical Atomic Clocks”, https://doi.org/10.1016/j.crhy.2015.03.012, Comptes Rendus Physique, Vol. 16, 5, 2015, pp. 506-515, 2015
6. Kimura, M., ”Development of the software correlator for the VERA system II”, IVS NICT-TDC News 35, pp.22-25, http://www2.nict.go.jp/sts/stmg/ivstdc/news_28/pdf/tdcnews_28.pdf, 2007.
7. Kondo, T., and K. Takefuji, “An algorithm of wideband bandwidth synthesis for geodetic VLBI”, Radio Sci., 51, doi:10.1002/2016RS006070, 2016.
8. Hobiger T., Y. Koyama, and T. Kondo, ”MK3TOOLS & NetCDF - storing VLBI data in a machine independent array oriented data format”, Proceedings of the 18th European VLBI for Geodesy and Astrometry Work Meeting, ISSN 1811-8380, pp. 194-195, 2007.
9. Ming H. Xu, et al., “The impacts of source structure on geodetic parameters demonstrated by the radio source 3C371”, J. Geod., 91, 767, https://doi.org/10.1007/s00190-016-0990-x, 2017.
10. Sekido M., “NICT VLBI Analysis Center Report for 2015-2016”, in International VLBI Service for Geodesy and Astrometry 2015+2016 Biennial Report, edited by K. D. Baver, D. Behrend, and K. L. Armstrong, NASA/TP-2017-219021, pp.241-244, 2017.
11. Petit. G., et al., “1×10^{-16} frequency transfer by GPS PPP with integer ambiguity resolution”, Metrologia 52 301.309, doi:10.1088/0026-1394/52/2/301, 2015.
12. Hobiger, T., et al., “c5++ - Multi-technique Analysis Software for Next Generation Geodetic Instruments”, IVS 2010 General Meeting Proceedings - VLBI2010: From Vision to Reality, NASA/CP-2010-215864, pp. 212-216, 2010.