GALAXY AND KSP: REAL-TIME VLBI TRIALS IN JAPAN

Hisao Uose[(1)], **Kazunari Irie**[(1)], **Sotesu Iwamura**[(1)], **Tetsuro Kondo**[(2)], **Junichi Nakajima**[(2)], **Hitoshi Kiuchi**[(2)], **Noriyuki Kawaguchi**[(3)], **Kenta Fujisawa**[(3)], **Yasuhiro Murata**[(4)], **Hisashi Hirabayashi**[(4)]

(1) NTT Laboratories, 3-9-11 Midori-cho, Musashino-shi, Tokyo 180-8585, Japan E-mail: uose.hisao@lab.ntt.co.jp
(2) Communications Research Laboratory, 4-2-1 Nukui-Kitamachi, Koganei-shi, Tokyo 184-8795, Japan
(3) National Astronomical Observatory, 2-21-1 Osawa, Mitaka-shi, Tokyo 181-8588, Japan
(4) Institute of Space and Astronautical Science, 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan

ABSTRACT

Since 1995 we have been conducting experiments on real-time VLBI (very long baseline interferometry) using a large scale network testbed having the maximum speed of 2.4Gbps. With the real-time data transmission using high-speed communications network, the bottleneck resulted from the limited data rates with the conventional magnetic tape based VLBI system can be removed. Two applications of VLBI, geodesy and radio astronomy, are being pursued with our trial and extensive research items regarding the real-time VLBI technology are being conducted. So far, through the experiments using the developed real-time VLBI system, great improvement in observation performance has been achieved.

INTRODUCTION

In 1995, NTT Laboratories have started a joint research project on ultra high-speed communications with national research organizations using a large scale network testbed having the maximum speed of 2.4Gb/s. Among many applications tried in the project, the real-time VLBI (very long baseline interferometry) has proved to be benefited greatly from the high performance communications technologies. With the real-time data transmission using high-speed communications network, the bottleneck resulted from the limited data rates in the conventional magnetic-tape-based VLBI system can be removed. By utilizing the ultra wide bandwidths of the communications network, the performance of the observation system can be upgraded significantly.

In the second phase of the project started in 1998 with Communications Research Laboratory (CRL), National Astronomical Observatory of Japan (NAOJ) and Institute of Space and Astronautical Science (ISAS), therefore, the focus is placed on the advancement of the real-time VLBI technology. While the KSP (Key Stone Project) led by CRL mainly focused on the geodesy and earth science research, GALAXY was a joint effort of all participating organizations to achieve the most advanced virtual radio telescope by combining major antennas and processing units available in Japan. NTT has constructed a dedicated ATM network spanning Kanto/Shin-etsu area and provided the network facilities to its research partners together with the necessary technologies to adapt their equipment to connect to the experimental network. The experimental network connects the NTT R&D centers and participating research organizations with 2.4Gb/s circuits, repeaters, ATM Switches and high-performance IP routers. Total of six antennas belonging to the partner organizations are used for the trials. They include Nobeyama 45m, Usuda 64m and Kashima 34m antennas shown in Fig. 1.

Extensive research items regarding the real-time VLBI technology are being conducted, together with the scientific observations using our experimental observation system. So far, through the experiments using the developed real-time VLBI system, great improvement in observation performance has been achieved. This paper explains the outline of this unique research project and addresses the future plan of our research activities.

NAOJ Nobeyama 45m

CRL Kashima 34m

ISAS Usuda 64m

11m antennas for KSP
(Koganei, Tateyama, Miura, Kashima)

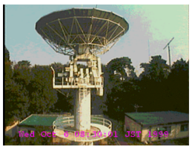

Fig. 1 Antennas used for our Trials

REALTIME VLBI APPLICATIONS

With the conventional magnetic-tape-based VLBI system, the amount of observation data was restricted by the data rate and storage capacity of the data recorder used for storing observed radio signals at each antenna site, limiting the performance of the whole observation system. With the real-time VLBI system directly connecting antennas and data processing units with communications network, however, this restriction can be removed and the larger amount of data can be utilized for the analyses. In addition, real-time cross correlation during the observation allows researchers to check the status and condition of their observation at the spot. Consequently, real-time VLBI brings great advantages over the conventional tape-based system in both aspects of system performance and observation efficiency. We have two applications using the real-time VLBI in our project, geodesy and radio astronomy.

Geodesy (KSP: Key Stone Project)

The KSP is a joint trial of CRL and NTT to implement a high precision crustal deformation measurement system using real-time VLBI. For this project CRL has constructed four measurement stations, each of which has dedicated 11m antenna, in Kanto (larger metropolitan Tokyo) area. By connecting those antennas with the central cross correlator located in CRL Koganei, Tokyo, measurements with very high resolutions have been made possible. The net data rate from each antenna is 256Mb/s (total rate of 1Gb/s) and the signals are routed to CRL Koganei through NTT Musashino Research and Development Center and processed real-time with a hardware cross correlator. With this observation system, the crustal deformation in Kanto area can be measured with the precision of millimeters in a couple of hours. At the same time, the automatic measurement was made possible by reducing the turn-around time of the data processing brought by the real-time correlation.
Since 1996 till the end of 2001, regular measurements (every other days) have been conducted using the KSP network and the large amount of observed data is publicly offered to the earth science community through the CRL web site. Last year, a major deformation due to a sudden volcanic activity around Izu Island was clearly observed with this system.

Radio astronomy (GALXY Projects)

This is a joint effort of NTT, NAOJ, CRL and ISAS to implement the world's largest virtual radio telescope having ultra-high resolution/sensitivity by combining conventional VLBI technology and the newest Gb/s class communications network. By adopting the VLBI technology, a large virtual telescope can be constructed with multiple antennas. The synthesized virtual telescope has the same angular resolution of one very large telescope with the diameter which is equal to the distance between the remote antennas, in the case of Kashima-Usuda baseline, 208km.

The on-site processing/observation brought by the real-time VLBI has allowed us to conduct very flexible and efficient VLBI observations, by constantly checking the obtained data while we are tracking the target radio source. This is only possible with the real-time VLBI technology. We can use a number of terrestrial antennas together with a space radio telescope HALCA using our network. The first fringe (cross correlation) was detected in 1997 between the signals received by a terrestrial antenna (Usuda 64m) and a satellite antenna (HALCA). Real-time correlation has been successfully established among large terrestrial antennas (Usuda 64m, Nobeyama 45m and Kashima 34m) in 1998. A variation of signal strength of a bursty radio source was successfully observed in a session of the real-time VLBI observation in 1999. Fig.2 shows the current configuration of the experimental network.

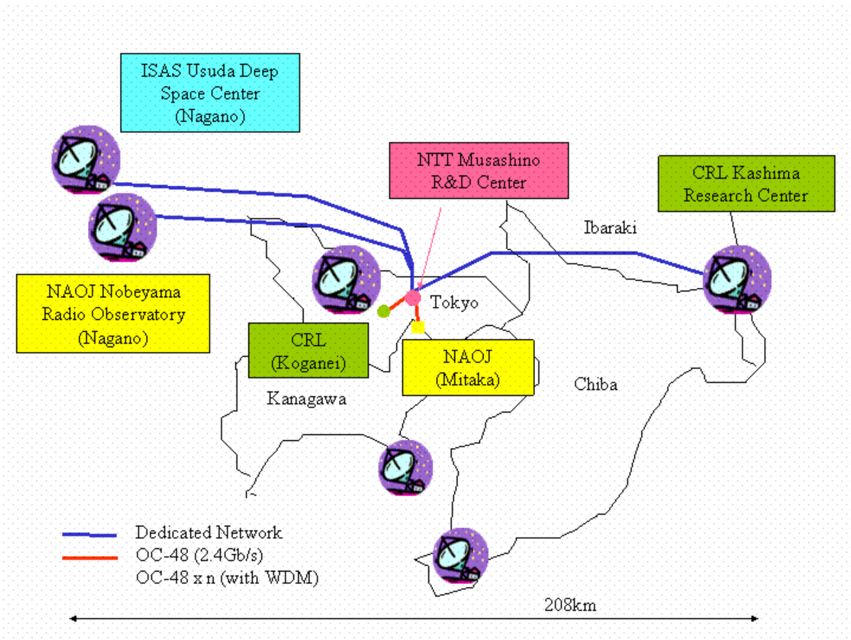

Fig. 2 Current Experimental Network for KSP and GALAXY

NETWORKING ISSUES

Internet VLBI and distributed computing

In the first phase of the project, we used ATM (Asynchronous Transfer Mode) technology to carry radio signals. The ATM technology has the precise bandwidth management capabilities enabling a very stable transmission required for the critical applications like real-time VLBI. In the second phase, however, we started to study to utilize IP (Internet Protocol) technologies extensively within our experimental network together with ATM.

To make the real-time VLBI experiment more affordable and widespread, the use of IP technologies will be effective, because research and education networks around the world are rapidly increasing their capacities and those networks are accessible from major public research organizations around the world. Standing on this viewpoint, we are developing very high-speed VLBI data transfer system using IP technology which will be applicable to real-time VLBI system. This involves challenging research issues including high speed IP stream transmission and advanced network resource management. In addition, we've started the research on distributed processing using a number of PCs connected by high performance network for calculating cross correlation of the radio signals. This approach is in line with the GRID computing concept.

At the moment, we have successfully conducted a real-time VLBI observation between Usuda 64m and Kashima 34m antennas using our IP transmission system with the speed of 128Mb/s. The transmission speed can be easily upgraded because we employed a modular architecture that splits a very high-speed data stream into multiple IP sub-streams and send the data in parallel in the network.

Adoption of photonic technologies

NTT Laboratories have a large R&D force in the field of photonic networking technologies. We've just started to cooperate with them to further strengthen the infrastructure of our network testbed. Now the new pieces of WDM (Wavelength Division Multiplexing) equipment are being deployed in our network with an innovative AWG device developed at our laboratories. This will allow us to use more bandwidth for the future experiments.

CONCLUSIONS

In June last year, we have successfully achieved the first real-time VLBI observation with the processing speed of 1Gbps in the world, using Usuda 64m antenna and Kashima 34m antenna. This achievement has a great significance opening up a new vista in the field of VLBI radio astronomy by improving the detection sensitivity of the observation system. The detection of the very weak radio sources will also accelerate the study to construct space-time standard infrastructure in space including the real-time and high time-resolution determination of the earth orientation parameters.

We plan to further improve the detection sensitivity of the real-time VLBI observation system by raising the transmission / processing speeds up to 2Gb/s this year in parallel with the upgrading of the experimental network. The development of "Internet VLBI" systems and the distributed cross-correlation system using the networked computers are other targets. With the success of IP VLBI data transmission, the possibility of realizing an international real-time VLBI observation system has come into view. In addition, with the combination of distributed data analyses and IP data transmission / packet routing, a completely new type of VLBI observation will be possible. For example, IP multicast can be used to distribute observed radio signals to a large number of cross correlators in the Internet, many of which will be ordinary PCs equipped with mathematical software conducting necessary calculations on demand.

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