High Speed Data Transmission and Processing Systems for e-VLBI Observations

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Outline

- What is e-VLBI?
- How?
  - K5 VLBI System
  - Network
- Test Experiments
  - Jan.31-Feb.1, 2003 KASHIMA-KOGANEI
  - Mar.25, 2003 KASHIMA-WESTFORD
- Future Plan
The Very-Long Baseline Interferometry (VLBI) Technique
(with traditional data recording)

The Global VLBI Array
(up to ~20 stations can be used simultaneously)
**VLBI Science**

**ASTRONOMY**
- Highest resolution technique available to astronomers – tens of microarcseconds
- Allows detailed studies of the most distant objects

**GEOODESY**
- Highest precision (few mm) technique available for global tectonic measurements
- Highest spatial and time resolution of Earth’s motion in space for the study of Earth’s interior
  - Earth-rotation measurements important for military/civilian navigation
  - Fundamental calibration for GPS constellation within Celestial Ref Frame
Why e-VLBI?

To improve timeliness of global VLBI data processing

R1 & R4 Time Delay Over Time
September 11, 2002 - CCT

Delay in days
Why e-VLBI?

- Currently it takes at least 2 weeks to process (mainly shipping time)

- If it become 2 hours, it will improve accuracy of
  - positioning
  - navigation
  - real-time orbit determination of satellites and spacecrafts

- It potentially expands correlation/observation capacity
  - Currently ~8 stations with hardware correlator
  - Easy scalability with PC/distributed software correlator
  - No Recording Speed Limit with real-time correlation
e-VLBI with Satellite Link

- For Geodesy/Astronomy
  - e-VLBI with remote/isolated sites
  - distributed correlation processing

- For Network Research
  - ideal high volume data set for network research
  - research for adaptive transmission protocol
  - low QoS requirements
    - data loss
    - large/variable transmission delay
Typical bit-rate statistics on network

Usage >20Mbps less than 1% of the time

Conclusion: Average network usage is only a few % of capacity
VLBI Systems for e-VLBI

K3 System
- 1983~
  - Longitudinal Recorder
  - Open Reel Tapes
  - Hardware Correlator

K4 (KSP) System
- 1990~
  - Rotary Head Recorder
  - Cassette Tapes
  - Hardware Correlator
  - e-VLBI with ATM

K5 System
- 2002~
  - PC based system
  - Hard Disks
  - Software Correlator
  - e-VLBI with IP
e-VLBI with ATM Network
(1998~2001)

ATM VLBI interface (left)
and Correlator (right)

Distance between Kashima and Tateyama

100km
K5 Data Acquisition System for e-VLBI with IP

- 4 Pentium PCs
  - CPU: Pentium-4
    - 1.2GHz (1st Unit)
    - 2.4GHz (2nd Unit)
  - OS: FreeBSD (Linux is also possible)
  - An IP-VLBI board (PCI) in each PC
  - 120Gbyte HDx4x4 ~ 2.8days@64Mbps

- 16ch base-band signal amplifier

- Standard Signal Distributor
  - 10MHz and 1PPS signals for 4 units
PCI Data Sampling Board (IP-VLBI Board)

Left : Main board
Right : Auxiliary board
### Specifications of the board

<table>
<thead>
<tr>
<th>Reference signals</th>
<th>10MHz  +10dBm, 1PPS</th>
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</thead>
<tbody>
<tr>
<td># of INPUT CH</td>
<td>1 - 4ch</td>
</tr>
<tr>
<td>A/D</td>
<td>1, 2, 4, 8 bits</td>
</tr>
<tr>
<td>Sampling Freq.</td>
<td>40kHz, 100kHz, 200kHz, 500kHz, 1MHz, 2MHz, 4MHz, 8MHz, 16MHz</td>
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</tbody>
</table>
Test Experiments 1

- Jan. 31-Feb. 1, 2003
  - Kashima11m(K5)-Koganei11m(K5)
  - 24 hours, 56Mbps
  - Comparison with K4
K4-K5 comparison

Offset = 176 psec
RMS = 72.7 psec
K4-K5 comparison

Delay Residual

Data Analysis Results

<table>
<thead>
<tr>
<th></th>
<th>Baseline Length</th>
<th>Delay RMS</th>
<th>Delay Rate RMS</th>
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<tbody>
<tr>
<td>K4</td>
<td>109099657.0 mm</td>
<td>76 psec</td>
<td>136 fsec/sec</td>
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<tr>
<td>K5</td>
<td>109099641.2 mm</td>
<td>33 psec</td>
<td>92 fsec/sec</td>
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</table>
Test Experiments 2

- Mar. 25, 2003 (evlbi4)
  - Westford (Mk5)-Kashima34m(K5), 2 hours, 56Mbps
  - Fringes were found on Mar. 27!
<table>
<thead>
<tr>
<th>Source Name</th>
<th>Duration (sec)</th>
<th>File Size (Mark5)</th>
<th>File Size (K5)</th>
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<tr>
<td>1</td>
<td>4C39.25</td>
<td>90</td>
<td>1,620 Mbytes</td>
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<tr>
<td>2</td>
<td>1736+455</td>
<td>200</td>
<td>3,600</td>
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<tr>
<td>3</td>
<td>1357+769</td>
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<tr>
<td>4</td>
<td>0059+581</td>
<td>250</td>
<td>4,500</td>
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<td>5,580</td>
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<tr>
<td>Total</td>
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<td>5,034</td>
<td>90,612 Mbytes</td>
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</table>

File Transfer ~ 20 hours

Delay = 234 msec
Buffer Size = 64 kbytes
Speed
  = 2.2 Mbps / Connection
  = 11 Mbps (5 connections)

Correlation ~ 20 hours with 1 PC

Bandwidth Synthesis ~ 10 min.

Data Analysis ~ 1 hour

UT1-TAI
  = -32338.7280 +/- 23.90 (micro sec)
Future Plan

- Repeat ftp-VLBI with Kashima-Westford a few times
  - Speed up by expanding buffer size
  - Try 256 Mbps observations
- Develop Correlator CPU Array System in 2003
- Software developments for real-time data transfer in 2003
- Regular (weekly) Mk5-K5 e-VLBI using Tsukuba-Westford baseline in 2004

Acknowledgements

- Internet2
- SuperSINET
- Galaxy team (CRL, NTT, NAO, and ISAS)
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