Results of test e-VLBI experiments with the K5 VLBI system

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Outline

- Why e-VLBI?
- What is K5?
- Network
- Test Experiments
  - Jan.31-Feb.1, 2003 Kashima-Koganei
  - Feb.25, 2003 Kashima-Westerbork
  - Mar.25, 2003 Kashima-Westford
- Future Plan
Why e-VLBI?

- Currently it takes at least 2 weeks to process global geodetic VLBI sessions (mainly shipping time).

- If it becomes 2 hours, it will improve accuracy of:
  - Earth Orientation Parameters at present
  - real-time orbit determination of satellites and spacecrafts
  - positioning
  - navigation

- 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
Why e-VLBI?

To improve timeliness of global VLBI data processing

R1 & R4 Time Delay Over Time
September 11, 2002 - CCT
What is K5?

K3 System
- 1983~
- Longitudinal Recorder
- Open Reel Tapes
- Hardware Correlator
- KSP, VSOP, Gigabit, VERA

K4 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
K5 Family: Concept

**ADS1000**
(1024M sample/sec 1ch 1bit or 2bits)

**ADS2000**
(64M sample/sec 16ch 1bit or 2bits)

**IP-VLBI Board**
(~16M sample/sec ~4ch ~8bits)

PC: Data Acquisition
Correlation

Correlator
other DAS

Internet
e-VLBI with K4
ATM Network (1998~2001)

ATM VLBI interface (left) and Correlator (right)

Distance between Kashima and Tateyama

100km

Koganei

Kashima

Miura

Tateyama
K5 Data Acquisition System for e-VLBI with IP

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

- **3 complete units**
  - 2 at Kashima and 1 at Tsukuba

- **4 additional units planned**
  - Syowa10, Aira10, Chichi10, Shintotu3

- **Several experimental units**
  - Koganei11, Gifu11, Usuda64, Yamaguchi32, Tomakomai11, Algonquin, Mizusawa20
K5 PC-based Data Acquisition Terminal

- 7625A (Reference signal distributor)
- 7626 (16ch video amps)
- Rack mount PC with an IP-VLBI board (9260) and 4 removable HDD x 4
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>
</tr>
</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>
</tr>
</tbody>
</table>
## Characteristics of K5 Terminal

<table>
<thead>
<tr>
<th>Item</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference signals</td>
<td>10MHz (5MHz), 1PPS</td>
</tr>
<tr>
<td>Number of input channels</td>
<td>16</td>
</tr>
<tr>
<td>Low pass filter</td>
<td>4MHz / 8MHz</td>
</tr>
<tr>
<td>Sampling frequency</td>
<td>40kHz, 100kHz, 200kHz, 500kHz, 1MHz, 2MHz, 4MHz, 8MHz, 16MHz</td>
</tr>
<tr>
<td>A/D resolution (bit)</td>
<td>1, 2, 4, 8</td>
</tr>
<tr>
<td>Hard disk drives</td>
<td>120GB (minimum)/ch total &gt; 1.92TB</td>
</tr>
<tr>
<td>Maximum sampled data rate</td>
<td>256Mbps (512Mbps)</td>
</tr>
<tr>
<td>Real-time VLBI</td>
<td>supported</td>
</tr>
<tr>
<td>Typical operation modes</td>
<td>16ch x 4Mbps 16ch x 8Mbps 16ch x 16Mbps</td>
</tr>
<tr>
<td>VSI in/out</td>
<td>in : ready, out : under development</td>
</tr>
</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>
</tr>
</thead>
<tbody>
<tr>
<td>K4</td>
<td>109099657.0 ± 6.7mm</td>
<td>76 psec</td>
<td>136 fsec/sec</td>
</tr>
<tr>
<td>K5</td>
<td>109099641.2 ± 3.2mm</td>
<td>33 psec</td>
<td>92 fsec/sec</td>
</tr>
</tbody>
</table>
Test Experiments 2

- Feb. 25, 2003 (n031l)
  - Westerbork (Mk5)
    - Kashima34m(K5)
  - 3 scans
  - 16MHz bandwidth
    - x 2 ch.
  - 32MHz sampling
  - 2 bits/sample
  - Total 128 Mbps
Test Experiments 3

- 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>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4C39.25</td>
<td>1,620 Mbytes</td>
<td>180 Mbytes x 4</td>
</tr>
<tr>
<td>2</td>
<td>1736+455</td>
<td>3,600</td>
<td>400 x 4</td>
</tr>
<tr>
<td>3</td>
<td>1357+769</td>
<td>1,620</td>
<td>180 x 4</td>
</tr>
<tr>
<td>4</td>
<td>0059+581</td>
<td>4,500</td>
<td>500 x 4</td>
</tr>
<tr>
<td>5</td>
<td>2234+282</td>
<td>5,580</td>
<td>620 x 4</td>
</tr>
<tr>
<td>6</td>
<td>1300+580</td>
<td>2,520</td>
<td>280 x 4</td>
</tr>
<tr>
<td>7</td>
<td>0955+476</td>
<td>1,620</td>
<td>180 x 4</td>
</tr>
<tr>
<td>8</td>
<td>2113+293</td>
<td>5,400</td>
<td>600 x 4</td>
</tr>
<tr>
<td>9</td>
<td>1739+522</td>
<td>9,000</td>
<td>1,000 x 4</td>
</tr>
<tr>
<td>10</td>
<td>1357+769</td>
<td>1,620</td>
<td>180 x 4</td>
</tr>
<tr>
<td>11</td>
<td>0059+581</td>
<td>4,860</td>
<td>540 x 4</td>
</tr>
<tr>
<td>12</td>
<td>2234+282</td>
<td>9,180</td>
<td>1,020 x 4</td>
</tr>
<tr>
<td>13</td>
<td>1044+719</td>
<td>1,4112</td>
<td>1,568 x 4</td>
</tr>
<tr>
<td>14</td>
<td>1128+385</td>
<td>3,240</td>
<td>360 x 4</td>
</tr>
<tr>
<td>15</td>
<td>1300+580</td>
<td>2,340</td>
<td>260 x 4</td>
</tr>
<tr>
<td>16</td>
<td>0955+476</td>
<td>1,620</td>
<td>180 x 4</td>
</tr>
<tr>
<td>17</td>
<td>2113+293</td>
<td>7,020</td>
<td>780 x 4</td>
</tr>
<tr>
<td>18</td>
<td>1739+522</td>
<td>9,540</td>
<td>1,060 x 4</td>
</tr>
<tr>
<td>19</td>
<td>1357+769</td>
<td>1,620</td>
<td>180 x 4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>90,612 Mbytes</td>
<td>40,272 Mbytes</td>
</tr>
</tbody>
</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 (at 20:00 UT)**

= -32338728.0 +/- 23.90
  (micro sec)

cf. **UT1R-TAI (at 00:00 UT)**

= -32337951 micro sec. (Mar. 25)
= -32338610 micro sec. (Mar. 26)
(IERS Bulletin B 183, 2 May, 2003)
Future Plan: Correlator

- Array of multiple PCs
  - Distributed Processing
  - Scalable
  - Upgradeable
  - Replaceable

K-5 Correlator
Future Plan: Correlator

One example of many possible configurations

### Master control file: example

<table>
<thead>
<tr>
<th>Obs Time</th>
<th>Dur.</th>
<th>Source</th>
<th>Baseline</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>001 12:20:00</td>
<td>60</td>
<td>3C273B</td>
<td>KAS-WES</td>
<td>Completed</td>
</tr>
<tr>
<td>001 12:20:00</td>
<td>90</td>
<td>3C273B</td>
<td>KAS-WET</td>
<td>Completed</td>
</tr>
<tr>
<td>001 12:20:00</td>
<td>90</td>
<td>3C273B</td>
<td>WES-WET</td>
<td>Completed</td>
</tr>
<tr>
<td>002 12:25:00</td>
<td>90</td>
<td>3C84</td>
<td>KAS-WES</td>
<td>Proc. at 01</td>
</tr>
<tr>
<td>002 12:25:00</td>
<td>90</td>
<td>3C84</td>
<td>WES-WET</td>
<td>Proc. at 02</td>
</tr>
<tr>
<td>003 12:30:00</td>
<td>90</td>
<td>4C39.25</td>
<td>KAS-WES</td>
<td>Data Ready</td>
</tr>
<tr>
<td>003 12:30:00</td>
<td>90</td>
<td>4C39.25</td>
<td>KAS-WET</td>
<td>Data Ready</td>
</tr>
<tr>
<td>003 12:30:00</td>
<td>90</td>
<td>4C39.25</td>
<td>WES-WET</td>
<td>Data Ready</td>
</tr>
<tr>
<td>004 12:35:00</td>
<td>90</td>
<td>3C345</td>
<td>KAS-WES</td>
<td>Waiting Data</td>
</tr>
</tbody>
</table>

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Site B

Site A

Site C

Mater Controler

Data Relay

Data Archive

Correlation Processing

One example of many possible configurations
Current K5 Data Format

- Header (64 bits)
- Sync pattern 1 (FFFFFFFF)
- Time of day (sec)
- Sync block 2 (8B)
- Sampled data (40000-64000000 bits)
- Reserved
- F sample AD bits
Considerations for Data Format

- Use RTP for Framework
- Define Payload Formats for e-VLBI

RTP Header

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>15</th>
<th>16</th>
<th>31</th>
</tr>
</thead>
<tbody>
<tr>
<td>V=2</td>
<td>P</td>
<td>X</td>
<td>CC</td>
<td>M</td>
<td>Payload Type</td>
<td>Sequence number</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Timestamp
- Synchronization source (SSRC) identifier
- Contributing source (CSRC) identifiers
  
  V : Version : Current Version is 2
  P : Padding : Packet contains one or more additional padding octets at the end if this bit is set
  X : Extension : Fixed header is followed by exactly one header extension if this bit is set
  CC : CSRC count : Number of CSRC identifiers that follow the fixed header
  M : Marker : intended to allow significant events to be marked in the packet stream
Considerations for Data Format

- Advantages of using RTP
  - designed for high speed data streams which do not require high QoS.
  - definition of payload format for individual application is allowed.
  - can expect to use existing routers and gateways.
  - the same payload format can be used for e-VLBI and conventional VLBI.
    - e-VLBI specific features (sync word, sequence number, etc.) can be transferred in RTP header fields.
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 for example

Acknowledgements

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