Multi-GNSS Opportunities and Challenges

Ali Al-Shaery¹,²
Shaocheng Zhang³
Samsung Lim¹
Chris Rizos¹

¹School of Surveying and Spatial Information System, the University of New South Wales, Sydney, NSW, Australia
²Umm Al-Qura University, Makkah, Saudi Arabia
³SPACE Research Centre, RMIT University, Australia
Multi-GNSS Opportunities and Challenges

- Introduction
- Opportunities
- Challenges and Solutions
- Concluding remarks
Introduction

GLONASS
FOC on
08/12/2011

Source: gislounge.com
Introduction

2 Operational Satellites in Space since Oct 2011
FOC on 2020

FOC since Dec 2011

11 Operational Satellites in Space since Feb 2012
FOC on 2020

FOC since July 1995

Source: kellogreport.com

http://www.colorado.edu/geography/gcraft/notes/gps/foc.txt
http://www.beidou.gov.cn/xtjs.html
http://www.esa.int/esaNA/galileo.html
Opportunities

• Number of visible satellites increase >>> satellite geometry improves >>> positioning accuracy improves

• Increasing availability of GLONASS products from IGS analysis centres >>> real-time application becomes possible

• More and more GPS+GLONASS CORS networks >>> precise GNSS applications in post-mission and real-time
Challenges

- GPS
  - Coordinates Reference Frame
  - Time Reference Frame

- GLONASS
  - Signal Structure (FDMA)
  - Coordinates Reference Frame
  - Time Reference Frame
Challenges

- Inter-channel bias
- Receiver Clock Error
- FDMA
- Inter-channel bias
Receiver Clock Error

- **Estimation**
  - System 1
    \[
    P_{rm,1}^{GPS, pq} = \rho_{rm,1}^{pq} + \varepsilon_{rm,1}^{pq}
    \]
    \[
    P_{rm,1}^{GLO, x} = \rho_{rm,1}^{x} + cdt_{rm} + \varepsilon_{rm,1}^{x}
    \]
    \[
    \varphi_{rm,1}^{GPS, pq} = \frac{f_1^x}{c} \rho_{rm,1}^{pq} + N_{rm,1}^{pq} + \tau_{rm,1}^{pq}
    \]
    \[
    \varphi_{rm,1}^{GLO, xy} = \frac{f_1^x}{c} \rho_{rm,1}^{x} - \frac{f_1^y}{c} \rho_{rm,1}^{y} + \left( \frac{f_1^x}{c} - \frac{f_1^y}{c} \right) cdt_{rm} + N_{rm,1}^{xy} + \tau_{rm,1}^{xy}
    \]

- **Elimination**
  - System 2
    \[
    P_{rm,1}^{GPS, pq} = \rho_{rm,1}^{pq} + \varepsilon_{rm,1}^{pq}
    \]
    \[
    P_{rm,1}^{GLO, xy} = \rho_{rm,1}^{xy} + \varepsilon_{rm,1}^{xy}
    \]
    \[
    \Phi_{rm,1}^{GPS, pq} = \rho_{rm,1}^{pq} + \frac{c}{f_1} N_{rm,1}^{pq} + \tau_{rm,1}^{pq}
    \]
    \[
    \Phi_{rm,1}^{GLO, xy} = \rho_{rm,1}^{pq} + \frac{c}{f_1^x} N_{rm,1}^{x} - \frac{c}{f_1^y} N_{rm,1}^{y} + \tau_{rm,1}^{xy}
    \]
## Receiver Clock Error

### Summary of static RTK test parameters

<table>
<thead>
<tr>
<th></th>
<th>CHUN029</th>
<th>BTRG029</th>
<th>CHPB029</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data length</strong></td>
<td>24 hr</td>
<td>24hr</td>
<td>24hr</td>
</tr>
<tr>
<td><strong>Obs. Type</strong></td>
<td>L1+L2</td>
<td>L1+L2</td>
<td>L1+L2</td>
</tr>
<tr>
<td><strong>Baseline Length</strong></td>
<td>4.4km</td>
<td>8.3km</td>
<td>9.7km</td>
</tr>
<tr>
<td><strong>Receiver Types</strong></td>
<td>Leica</td>
<td>Trimble</td>
<td>Leica</td>
</tr>
<tr>
<td><strong>Elevation mask</strong></td>
<td>15°</td>
<td>15°</td>
<td>15°</td>
</tr>
<tr>
<td><strong>Interval</strong></td>
<td>15s</td>
<td>15s</td>
<td>15s</td>
</tr>
</tbody>
</table>

(29\12\2011)
## Receiver Clock Error

Below are plots showing the receiver clock error over time for different baselines. Each plot represents the North, East, and Up components of the error for two systems (System 1 and System 2).

### Baseline: CHUN029
- **System 1**: Error (E) 0.006, (N) 0.005, (U) 0.013
- **System 2**: Error (E) 0.006, (N) 0.005, (U) 0.013

### Baseline: BTRG060
- **System 1**: Error (E) 0.007, (N) 0.010, (U) 0.021
- **System 2**: Error (E) 0.007, (N) 0.010, (U) 0.021

### Baseline: CHPB029
- **System 1**: Error (E) 0.008, (N) 0.006, (U) 0.019
- **System 2**: Error (E) 0.008, (N) 0.006, (U) 0.019

### Table: Standard Deviation (m)

<table>
<thead>
<tr>
<th>Baseline</th>
<th>System</th>
<th>E</th>
<th>N</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHUN029</td>
<td>System 1</td>
<td>0.006</td>
<td>0.005</td>
<td>0.013</td>
</tr>
<tr>
<td></td>
<td>System 2</td>
<td>0.006</td>
<td>0.005</td>
<td>0.013</td>
</tr>
<tr>
<td>BTRG060</td>
<td>System 1</td>
<td>0.007</td>
<td>0.010</td>
<td>0.021</td>
</tr>
<tr>
<td></td>
<td>System 2</td>
<td>0.007</td>
<td>0.010</td>
<td>0.021</td>
</tr>
<tr>
<td>CHPB029</td>
<td>System 1</td>
<td>0.008</td>
<td>0.006</td>
<td>0.019</td>
</tr>
<tr>
<td></td>
<td>System 2</td>
<td>0.008</td>
<td>0.006</td>
<td>0.019</td>
</tr>
</tbody>
</table>
Receiver Clock Error

(21/12/2011)
Receiver Clock Error

System 1

Fix Epochs: 72.03 %
Receiver Clock Error

Fix Epochs: 74.59 %

System 2

Easting (m) x 10^6
Northing (m) x 10^6
Inter-channel Bias

• Identification
• estimation
• calibration
Inter-channel Bias - Identification

21/12/2011
Inter-channel Bias - Identification

Fixed Epochs: 40.44 %

Easting (m) x 10^5

Northing (m) x 10^6

LE-LE Fixed
LE-LE Float
Inter-channel Bias - Identification

Fixed Epochs: 22 %
Inter-channel Bias - Identification

Fixed Epochs: 16.73 %
Inter-channel Bias - Estimation

(29\01\2012), 23hr, 15 sec
Inter-channel Bias - Estimation

\[ P_{rm,1}^{GPS,pq} = \rho_{rm}^{pq} + v_{rm,1}^{pq} \]

\[ P_{rm,1}^{GLO,pq} = \rho_{rm}^{pq} + \left( k^p - k^q \right) c \zeta_{rm} + v_{rm,1}^{pq} \]

\[ \Phi_{rm,1}^{GPS,pq} = \rho_{rm}^{pq} + \frac{c}{f_1} \left( N_{rm,1}^p - N_{rm,1}^q \right) + \epsilon_{rm,1}^{pq} \]

\[ \Phi_{rm,1}^{GLO,pq} = \rho_{rm}^{pq} + \frac{c}{f_1^p} N_{rm,1}^p - \frac{c}{f_1^q} N_{rm,1}^q + \left( k^p - k^q \right) c \gamma_{rm} + \epsilon_{rm,1}^{pq} \]

\( \gamma_{rm} \) CPH inter-channel bias expressed in metres by multiplying it by speed of light (c).

\( \zeta_{rm} \) PR inter-channel bias expressed in metres by multiplying it by speed of light (c).

GLONASS channel number for satellite (p) (-7~+6)

<table>
<thead>
<tr>
<th>Average values of inter-channel bias between mixed receivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEICA - Trimble</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>CPH (m)</td>
</tr>
<tr>
<td>-0.031</td>
</tr>
<tr>
<td>-0.024</td>
</tr>
</tbody>
</table>
## Inter-channel Bias - Calibration

![Graphs showing North, East, and Up movement over time with epoch and GPS time labels.](image)

<table>
<thead>
<tr>
<th>LEICA-TRIMBLE</th>
<th>Standard deviation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>With Correction</td>
<td>E: 0.006 N: 0.005 h: 0.013</td>
</tr>
<tr>
<td>Without Correction</td>
<td>E: 0.242 N: 0.193 h: 0.568</td>
</tr>
</tbody>
</table>
Inter-channel Bias - Calibration

<table>
<thead>
<tr>
<th>LEICA-TOPCON</th>
<th>Standard deviation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E</td>
</tr>
<tr>
<td>With Correction</td>
<td>0.006</td>
</tr>
<tr>
<td>Without Correction</td>
<td>0.344</td>
</tr>
</tbody>
</table>
Concluding Remarks

• Will these challenges become a real obstacle to an “interoperable GNSS world”?
  • Receiver clock error is well mitigated
  • Inter-channel bias still needs more attention from GNSS community.
• The answer may rely on a collaboration between GNSS analysis centres-academia-industry.