Multi-GNSS
Advantages, challenges and test solutions
MODERATOR

GRACE RYBAK
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SKYDEL

TALEN-X
COMMUNICATE - NAVIGATE - EXCEL
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[Logos for Skydel and Talen-X]
Multi-Constellation

Intro
## GNSS Status

<table>
<thead>
<tr>
<th>Constellations</th>
<th>Nominal number of satellites and type of orbits</th>
<th>Operational satellites</th>
<th>Number of signals</th>
<th>Number of frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS</td>
<td>24</td>
<td>31</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>GLONASS</td>
<td>24</td>
<td>24</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>BeiDou</td>
<td>27-MEO, 3-IGSO, 5-GEO</td>
<td>3-MEO, 6-IGSO, 6-GEO</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Galileo</td>
<td>30</td>
<td>17</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>QZSS</td>
<td>3-IGSO, 1-GEO</td>
<td>3-IGSO, 1-GEO</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>IRNSS/NavIC</td>
<td>4-IGSO, 3-GEO</td>
<td>4-IGSO, 3-GEO</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
Mid-2020s

- GPS
- GLONASS
- Galileo
- BeiDou
- NavIC
- QZSS
Multi-constellation: Benefits

- Availability
- Continuity
- Integrity
- Accuracy
- Robustness
- Speed up operation performance
- Opens new opportunities
Single Constellation
Multiple Constellations

- Galileo
- GPS
- GLONASS
- BeiDou
Challenges

✓ Intelligent algorithm in observation model
  • Multi-frequency
  • Multi-constellation

✓ Inter-system Biases
  • System clock
  • Inter-frequency
  • Ionosphere
  • Antenna phase center

✓ GNSS signal processing
  • Interferences and jammers
  • Spoofing
  • Authentication

✓ Constellations control
  • Time reference
  • Master constellation
Lock achieved with 6 satellites from 3 different constellations
Multi-Constellation and Jamming

Examples with GNSS receiver
4 MHz jammer
GNSS Receiver Response to Jamming on GPS and Galileo

- Type: Chirp
- $F_c = 1575.42$ MHz
- $B = 4$ MHz
- $J/S = 0 \ldots 40$ dB
- GPS L1 C/A, GLO G1, Gal E1, BDS B1
- Position Fix: Yes
GNSS Receiver Response to Jamming on GLONASS

- **Type**: Chirp
- **\( F_c \) = 1602 MHz**
- **\( B \) = 4 MHz**
- **\( J/S \) = 0 ... 40 dB**
- **GPS L1 C/A, GLO G1, Gal E1, BDS B1**
- **Position Fix**: Yes
# GNSS Receiver vs Constellation Input

<table>
<thead>
<tr>
<th></th>
<th>Receiver A</th>
<th>Receiver B</th>
<th>Receiver C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracking</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Position Fix</td>
<td>✔</td>
<td>✗</td>
<td>✔</td>
</tr>
<tr>
<td>GPS</td>
<td></td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>GLONASS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galileo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BeiDou</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Multi-Constellation and Spoofing

Examples with GNSS receiver
2D Positioning Error
Real Constellation GPS | Spoofer GPS
2D Positioning Error
Real Constellation GPS and Galileo | Spoofer GPS
Test Solutions for GNSS

GNSS Simulators
1 SDR Setup Example for Multi-Constellation Testing

GPS

GLONASS

Galileo

BeiDou II

Output 1
50 MHz Bandwidth

Output 2
50 MHz Bandwidth
Basic Setup

- Computer
  - 10 Gb Ethernet Link
  - NVIDIA GPU
- SDR
  - 10 MHz Ref. Clock
  - UBX-160 RF boards
- RF Cables
- Attenuators
- DC Block
- Combiner
SDX uses the PC’s GPU to generate – in real time – high-rate baseband signals that are converted to RF by the SDR.

### Channels per GPU Model

<table>
<thead>
<tr>
<th>Bandwidth</th>
<th>GTX 1050Ti</th>
<th>GTX 1080</th>
<th>GTX 1080Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 MHz</td>
<td>140</td>
<td>180</td>
<td>240</td>
</tr>
<tr>
<td>50 MHz</td>
<td>50</td>
<td>90</td>
<td>110</td>
</tr>
</tbody>
</table>
Jammer + Multi-Constellation

- GNSS and Jammers on the same radio
- Up to 120 dB of J/S ratio
- Multi-constellations
Spoofer + Multi-Constellation

2 SDX instances running on desktop computer

OCTOCLOCK-G
Timing Reference

10 MHz
PPS

Ettus X300 SDR #1
(Master)

Ettus X300 SDR #2
(Slave)

USB

GNSS RECEIVER
Device Under Test

GNSS Signal
Spoofing Signal
The flexible nature of SDX in relation to hardware allows a variety of configurations depending on the simulation needs of the client. Upgrades are easy, use COTS and “enable to grow” a configuration for additional capabilities.

### SDX Configuration Examples

<table>
<thead>
<tr>
<th>RF OUTPUTS</th>
<th>CAPABILITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 or 2</td>
<td>100+ satellites – multi-constellation – multi-frequency Advanced interferences</td>
</tr>
<tr>
<td>1 or 2</td>
<td>Synchronized Multi-Simulator</td>
</tr>
<tr>
<td>2-4</td>
<td>Large Signal Array (GNSS &amp; non-GNSS)</td>
</tr>
<tr>
<td>2-4</td>
<td></td>
</tr>
<tr>
<td>4+</td>
<td></td>
</tr>
</tbody>
</table>

Even the entry-level configuration can simulate 100 satellites with multiple constellations.
Conclusions

Take advantage from multi-constellations
Multi-constellation: GNSS

- For full advantage from multi-constellation, need better algorithms to process GNSS
- With no doubt, multi-constellation is more robust to jamming and especially to spoofing
- For multi-constellation testing, need to simulate all constellation in the same time and in perfect synch
- Software-defined solution is very flexible, allows for easy expansion and for interference simulation using the same radios
- Software-defined solution is cost effective
Multi-GNSS: Advantages, Challenges and Test Solutions

Tyler Hohman

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Multi-GNSS Testing

- New receivers are more powerful than ever
  - Concurrent multi- constellation tracking
  - Integrated jamming suppression
  - Spoofing detection
- Thousands of combinations of test
  - Jam C/A only, C/A + G1, E1 + C/A, etc.
  - How does my receiver perform?
  - When am I protected/vulnerable?
- Multiple environments to test in
- New capabilities require new methods to test
  - Automated testing
  - Easy scenario creation
  - Scalable flexibility
- Engineers could spend years testing
## New Multi-GNSS Receivers

<table>
<thead>
<tr>
<th>More complexity, more to test...</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Multi-frequency</strong></td>
</tr>
<tr>
<td>- L1, L2, L5</td>
</tr>
<tr>
<td>- A lot of HW required to generate</td>
</tr>
<tr>
<td><strong>Multiple codes</strong></td>
</tr>
<tr>
<td>- 8 for GPS alone!</td>
</tr>
<tr>
<td>- Expense to add licenses/HW</td>
</tr>
<tr>
<td><strong>Jamming suppression / detection built in</strong></td>
</tr>
<tr>
<td>- Require advanced jammers</td>
</tr>
<tr>
<td><strong>Spoofing resiliency</strong></td>
</tr>
<tr>
<td>- Double your hardware...</td>
</tr>
</tbody>
</table>
What to Test - Example

- Your GNSS receiver
  - Tracks L1 GPS, GLO, Galileo, and BeiDou
- Your environment
  - L1: 4 MHz jammer
  - GPS and Galileo jammed
  - GLO and BeiDou available
    - 1 spoofed
- Your performance
  - What happens to your NAV solution?
  - What is the tracking performance?
  - How can you compare results to truth? What is truth?

Graphic: Skydel
Applications

• Receiver performance
  • Acq, reacq
  • Tracking

• Interference resistance
  • How much jamming?
  • What constellations are relied on?

• Vulnerability studies
  • How does spoofing affect the Rx
  • What types are effective?

• Acceptance/Verification
Testing in Multiple Environments

- Laboratory
- Anechoic Chamber
- Over-the-air Field Test

Photos: U.S. Department of Defense. The appearance of U.S. Department of Defense (DoD) visual information does not imply or constitute DoD endorsement.
Laboratory

- Controlled environment
- High precision equipment
- Scalable and flexible configuration
- Easy to log and analyze data
- Repeatability
- Convenience
- Cost
- Challenges
  - Cannot test the full system

Photo: U.S. Department of Defense. The appearance of U.S. Department of Defense (DoD) visual information does not imply or constitute DoD endorsement.
Anechoic Chamber

- System level testing
  - AJAS
  - Equipment integrated into platform
  - Vehicle systems/sensors

- More real-world threats
  - Multiple angles of arrival

- Challenges
  - Cost of adding jamming and Multi-GNSS
  - Limited dynamics
  - Calibration

Photo: U.S. Department of Defense. The appearance of U.S. Department of Defense (DoD) visual information does not imply or constitute DoD endorsement.
Over-the-air Test Events

- Full integrated systems
  - AJAS
  - IMU/INS
  - Other aiding sensor inputs
- Dynamic scenarios
  - Vehicle trajectories
  - Threat trajectories
  - Various environments (land, sea, air, etc.)
  - Real multi-path
- Challenges
  - Frequency clearances
  - Often government hosted and by invitation only
  - Jam multiple frequencies
  - Spoofing multiple frequencies

Photo: U.S. Department of Defense. The appearance of U.S. Department of Defense (DoD) visual information does not imply or constitute DoD endorsement.
Automated Approach to Testing

- Control hardware
- Create scenarios
- Scalable hardware
- Collect data
- Generate reports

Flowchart showing the process of automated testing with a start, spoofing, recovery, and end stages.
SDR Approach from Lab to Field

- COTS SDRs keep cost low
- Flexible and scalable
  - IQ generation supports all constellations
  - Base is hardware capable of all GNSS signals
- Same system used in the lab can scale to work in a chamber and in the field
- Leverage prior engineering hours
  - Scenario development
  - Time to learn GUI, etc.
Scenario Creation
– Make it Easy

• One application that generates the whole environment
  • GNSS simulation
  • Jamming
  • Spoofing
  • Time synchronization
  • Trajectories

• Control your simulator and jammers
  • Adjust power levels and set noise floor
Collect Data – Common Format

• Every GNSS receiver is different
  • Data
  • Capabilities

• Output the data into a common format
  • Human readable
  • Easy to plot

• Accurately time stamp (0s-XXXs)

• Control multiple Units-Under-Test
  • Remove user interface besides connecting to system
Collect Data – Common Format
Spend Time Analyzing Data and Making Decisions

1. Automate the process to work for you
2. Come in each morning to auto generated plots and reports, not Excel files
3. Make decisions
Automation

- Creating test scenarios takes time
- Use the same test scenarios in all test environments
Conclusion

- There are many ways to test Multi-GNSS receivers
  - Lab
  - Chamber
  - Open environment

- New capabilities require new methods to test
  - Automated testing
  - Easy scenario creation
  - Scalable flexibility

- Some issues can arise with Multi-GNSS
  - Cost
  - How to test
  - Performance expectations
QUESTIONS?
CONTACT US

GRACE RYBAK
GRYBAK@NORTHCOASTMEDIA.NET

IURIE ILIE
IURIE.ILIE@SKYDELSOLUTIONS.COM

TYLER HOHMAN
THOHHMAN@TALEN-X.COM

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