GPS and Galileo developments on board the International Space Station with the Space Communications and Navigation (SCaN) testbed

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Introduction to the Space Communications and Navigation (SCaN) testbed and the experimentation
Objectives and challenges of the mission
Preliminary Design Considerations
Initial results from GPS and Galileo observations in space
Identified approach to Verification and Validation (V&V) activities
Conclusions and way forward
Introduction to the SCaN testbed

- **Navigation Capability:**
  - L1
  - L5

- **Communication Capability:**
  - S band
  - Ka band
Communication and ground support subsystem

Communications options

- There are two communication paths for the SCaN Testbed mission.
  - **Primary Link**: the ISS S-band and Ku-band links.
  - **Experimental Link**: with the SN and the NEN. This link will be scheduled directly by the STCC with the supporting elements.
**STRS Framework** abstracts the application software from the radio platform hardware.

The STRS software architecture uses three primary interfaces (1) the STRS API, (2) the STRS hardware abstraction layer (HAL) specification, and (3) the Portable Operating System Interface (POSIX).

The SDR Signal Processing HW is organized in:

- **Signal Processing Module (SPM)**: high rate WAVEFORM application components
- **General-purpose Processing Module (GPM)**: low rate signal processing WAVEFORM component and the managing SW.
Mission objectives and challenges

- Develop a GPS and Galileo multiconstellation Waveform
- Analyse both L1 and L5 opportunity
- Establish an international framework of cooperation between NASA and ESA
- Design innovative schemes for GNSS space acquisition and tracking considering the onboard limited resources
- Identify a strategy for integration, verification and validation considering the international cooperation and physical access constraints
- Perform in-orbit performance assessment and trade-off investigations
- Conclude and define future mission requirements and opportunities
Mission Schedule

Schedule for 2016 and 2017 activities

- **Task 1**: Design
  - lug. ’16
  - ott. ’16
- **Task 1**: Design and development
  - gen. ’17
- **Task 2**: Development and Integration
  - apr. ’17
- **Task 2**: V&V
- **Task 3**: Experimentation
  - lug. ’17
  - ott. ’17

Pre-flight Qualifications at NASA GRC

In-house verifications QASCOM/ESA

Waveform upload NASA GRC

Data Processing ESA/NASA

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High Level Mission Concepts

- First Dual Constellation SDR Receiver in Space
- Collection and Performance assessment of Galileo (and GPS) raw measurements (Pseudo Range, Carrier phase, etc.) in space,
- Computation of positioning in space (Position, Velocity and Time) and assessment of its performance.
- Aiding from ground via primary path
- Time Aiding from ISS avionics interface
- Final Choice for the L5/E5a Band
  - **Cons:** Less LOS, Lower PVT Availability, Higher FPGA resources, Limited equipment for L5 simulation
  - **Pros:** Better Power Budget, Better Code/CARRIER accuracy, New Concept for Space Test

System Design Concepts

- Communication subsystem and Ground Support Operations
- Navigation Subsystem (waveform)
Communication Subsystem

- Primary path communications link through international space station
  - Link traverses NASA Space Network including TDRSS
  - Data latency roughly 1 hour
- Experimental communications link DTE from ISS
  - Supports higher rates but with significantly less availability

Ground Support Operations

- XML Configuration (Ground to Space), 1 day Experiment
  - Tracking Parameters
  - Receiver Configuration
  - Aiding Data (Keplerian Parameters, GGTO,
- Binary Protocol for GNSS Data Observations and SW Logs
Navigation subsystem

**SW Main Modules**
- Receiver Manager (RM)
- Signal Processing Manager (SPM)
- Navigation Messages Manager (NMM)
- Navigation Manager (NM)

**FW Main Modules**
- Clock management
- Samples counter
- Carrier and code phase integrators
- Spreading code generator
- Numeric controlled oscillator (NCO)
- Parallel correlation for acquisition,
- Serial correlation for tracking,
Results from GPS and Galileo Observations in Space

- First Acquisition Test of GPS and Galileo SIS
  - GPS L1, SV 25
    - CN0 = 40 dBHz
  - GPS L5, SV 12
    - CN0 = 50 dBHz

- Doppler and Doppler Rate analyses
  - Max Doppler Observed ±36 KHz
  - Doppler Rate -20 Hz/s to +70 Hz/s
Results from GPS and Galileo Observations in Space

- Preliminary Dual Frequency Visibility Analysis
  - Visibility Analysis for all satellites above 30 deg
    - L1/E1
      - PVT Availability is > 99%
      - Mean Time with at least 4 Satellites in view 6 h
    - L5/E5a
      - PVT Availability is 64%
      - Mean Time with at least 4 Satellites in view 12 minutes

<table>
<thead>
<tr>
<th></th>
<th>GPS L1 + Galileo E1</th>
<th>GPS L5 + Galileo E5a</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVT Availability</td>
<td>99.76%</td>
<td>64.79%</td>
</tr>
<tr>
<td>MeanTime 4 Sats</td>
<td>21548.5s = 359.14 min</td>
<td>691.0864s = 11.52min</td>
</tr>
</tbody>
</table>

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Approach to verification and validation

- **Unit Level Testing**: will be executed for the two component of the Waveform (Software and Firmware). The Testing will be executed at Qascom premises in selected boards that are representative of the JPL SDR architecture.

- **System Level Testing**: will be executed at NASA premises. The objective is the verification of the integrated waveform components. Two integrated systems are available: the Experiment Development System (EDS) and the Ground Integration Unit (GIU). EDS will be verified with LVDS simulators. The GIU with RF simulation.

- **Experimentation**: this activity consists in the in-orbit validation and experimentation of the Waveform.
Conclusions

- Preliminary design has been identified to match both mission (SDR and STRS) and experiment objectives.
- In-orbit acquisition demonstrates the feasibility to acquire, track and experiment both GPS and Galileo L5 signals.
- An approach for integration and verification and validation that can satisfy both technical challenges and the international ESA-NASA context has been identified.
- In-Orbits experimentations are foreseen for early 2017, when 15 E5a Galileo satellites will be available and 12 L5 IIF Block GPS Satellites.
- The SCaN testbed and its evolutions are a unique opportunity to experiment navigation and communication SDR technologies in the space environment also in an international context.
Thank you!

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