GNSS Integrity Monitoring

Dr. Ilaria Martini
Institute of Communications and Navigation
German Aerospace Center

Email: Ilaria.Martini@dlr.de
Tel: +49 8153 28-2809

Rome, 22.06.2017
Outline
GNSS Integrity Monitoring

- DLR Background
- ARAIM Demonstrator
- GNSS Integrity Monitoring
- Results from Galileo measurements campaign
Background

DLR Research Activities

- Member of aviation and GNSS standardization bodies (EUROCAE, ICAO NSP, WG-EE, WGC)
- Consulting the European Commission on GNSS performance during the Galileo Initial Service Validation Review
- Participation as external expert to the Galileo Initial Service Declaration (ESA-GSA)
- Project with Spaceopal on the development of a Performance Monitoring Tool to be part of the Galileo ground segment
- Cooperation with ESA (ESA-DLR Working Group) on the Galileo Evolution
- Member of International USA-EU cooperation on Advanced RAIM Technical Working Group
ARAIM Demonstrator
ISM Generation

- System Faults identification and fault probability computation
- Constellation faults identification

- Statistic characterization of the Signal In Space error distribution
### ARAIM Demonstrator

**ISM Generation**

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<th>Pconst</th>
<th>Healthy Flag</th>
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- **Probability of a satellite fault**
- **3 faulty satellites**
- **Mean and variance of orbit/clock related SISRE**

![Chart 6](chart6.png)

**DLR.de • Chart 6**
**GNSS Integrity Monitoring—Martini - Rome, 22 June 2017**
Galileo Ranging Error
Initial Service Campaign

Signal In Space Ranging Error (March-August 2016)

Red Boxes show the performance when the anomalies are NOT detected and removed.
Galileo Satellite Clock Error
Satellite Anomalies

SV E26 presented clock anomalies from June 15th to July 20th 2016. Pronounced variations of physical clock AND associated errors of the broadcast clock offset values.

E24 presented a sudden change of the physical clock drift due to a clock switch on June 24th 2016 and it was not reflected in the broadcast clock offset until June 26th.
Galileo Satellite Clock Error
Precise Timing Facility Anomaly
Galileo Satellite Radiated Power
Galileo FOC – GSAT0206 – EIRP

GAL40890 - E1 RHCP - EIRP
12/11/2015 17:00:47 - 13/11/2015 00:58:40 UTC

EIRP [dBW]

Elevation Angle [Degree]

ascending

descending
Galileo Timing Performance
GGTO (and UTC) Accuracy

GGTO difference and GGTO frequency over 90 measurements every 16 min
Start: 20-05-2016; Stop: 19-07-2016
Thank you. Questions?

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Rome, 22.06.2017
GNSS Integrity and ARAIM Demonstrator Architecture

IGS Provider
- Reference Ephemeris and Clock
- Broadcast Ephemeris and Clock
- Antenna Phase Offset

GNSS Receiver

Signal Generator

SIS

Galileo

GPS

Glonass

ARAIM Demonstrator
- Threats Generator
- ISM Generator

Brdc Eph&Clk&URA Rinex Obs

Manipulated Rinex Obs & Nav

Eph&Clk

Ref Eph&Clk

Brdc Eph&Clk&URA

Antenna Phase Offset

Storage

User Processing Module

Analysis and Validation Module

Graphical User Interface

DLR.de • Chart 13
GNSS Integrity Monitoring– Martini - Rome, 22 June 2017
GNSS Performance Monitoring
Inputs and Ad-hoc Models for the Analysis

• **Inputs**
  - Broadcast ephemeris generated by DLR/TUM from global network of ~30 stations (MGEX/IGS)
  - Precise ephemerides generated at DLR from MGEX network (NAPEOS) for E1-E5a (daily solutions, 5min sampling)

• **Models**
  - A priori box model for solar radiation pressure (removes 1/rev orbit errors)
  - Radial antenna offsets for broadcast ephemerides in z-direction inferred from radial orbit offset
  - Differential Code Biases generated by DLR from IGS/MGEX network

<table>
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<th>Ephemeris</th>
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</table>

(IGS axis convention)
Signal In Space Ranging Error Performance

Time Series of Orbit & Clock Errors

\[ \text{sisre}_k = \sqrt{(w_R \cdot \Delta r_{R,k} - (\Delta cdt_k - \overline{\Delta cdt}))^2 + w_{T,N}^2 \cdot (\Delta r_{T,k}^2 + \Delta r_{N,k}^2)} \]

-k: satellite index
-R, T, N: radial, along and cross track
-w_R = 0.98, w_{T,N} = \sqrt{1/61}

-Epoch-wise constellation mean of clock offset difference
Galileo Satellite Orbit Error
Anomaly in the Radial Orbit Error