Galileo, an ace up in the sleeve for PPP techniques

September 15TH, 2016

Session D3: High Precision GNSS Positioning

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Introduction

- Precise Point Positioning Technique (PPP)
- GNSS Constellations Evolution

Multi-GNSS PPP Analyses

Galileo-only PPP Study

Conclusions
Two HA Positioning solutions: PPP and RTK

PPP is an absolute positioning technique

Worldwide or Regional coverage

Relies on the use of precise orbits & clocks + observations + detailed models

Sparse network of reference stations for service provision

PPP Technique

Precise Point Positioning

Monitor Stations

Precise GNSS Orbits and Clocks Generation

Code & Phase Observations

PPP Algorithm

HA Solution
- **magicPPP** provides the necessary end-to-end services and tools for PPP processing including:
  - Multi-constellation products provision
  - End-user applications for mobile devices and workstations
  - Analysis Tools to evaluate the service performances
  - Compatible with DF and SF receivers
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**GNSS Today**

94 Satellites

- GPS 32 sats
- GLONASS 27 sats
- BeiDou 20 sats
- Galileo 14 sats
- QZSS 1 sats

**GNSS Constellations Evolutions**

**GNSS Today**

**GPS**
- 32 sats

**GLONASS**
- 27 sats

**BeiDou**
- 20 sats

**Galileo**
- 14 sats

**QZSS**
- 1 sat

**94 Satellites**

**source: GSA**

Initial Operation Capability
- Early services for OS, SAR, PRS and demonstrator for CS
- 2016

In-Orbit Validation
- 4 fully operational satellites and ground segment
- 2014

Galileo System Testbed v1
- Validation of critical algorithms
- 2013

Full Operation Capability
- 30 fully operational satellites and ground segment
- 2020

Full Operation Capability
- 22 fully operational satellites and ground segment
- 2017

Full Operation Capability
- 22 fully operational satellites and ground segment
- 2016

Full Operation Capability
- 12 fully operational satellites and ground segment
- 2015

Full Operation Capability
- 12 fully operational satellites and ground segment
- 2014

Full Operation Capability
- 4 fully operational satellites and ground segment
- 2013

United States
- 94 Satellites

**UNCLASSIFIED INFORMATION**
On-going GNSS Evolutions

GPS and GLONASS modernization
- IIF satellites transmitting L2C and L5 signal → +Robustness
- Better on-board clocks
- Future CDMA GLONASS

Galileo Deployment and Initial Services
- 4 New satellites deployed during 2016 and 4 more expected for next year
- High performance on-board clocks will help to improve the PVT solutions at user level
- Initial Services Declaration

IGS and Analysis Centers are also moving in the multi-constellation direction.
Objective

Demonstrate the benefits of using Galileo for Precise Point Positioning Techniques

- Two types of analysis have been performed:
  1) Multi-constellation PPP ⇒ Benefits of introducing Galileo
  2) Galileo-only PPP ⇒ Achievable performances
PORTADA DE UNA SECCIÓN

ESTO ES UN EJEMPLO DE MULTI-GNSS PPP ANALYSES
Multi-GNSS PPP Analyses

**Static-user Scenarios**

- **Stations**
  - Continental Europe → WTZZ
  - North America → UCAL
  - Latitude > 60º → HOFN
  - Latitude < -4º → SEYG

- **Configurations**
  - GPS only
  - GPS + GLONASS
  - GPS + GALILEO
  - GPS + GLONASS + GALILEO

**Open sky scenarios**

- WTZZ
- UCAL
- HOFN
- SEYG
Multi-GNSS PPP Analyses

Continental Europe - WTZZ (Germany)

**Receiver:** JAVAD TRE_G3TH DELTA

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**Improvement:** 20-30%

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Multi-GNSS PPP Analyses

North America - UCAL (Canada)

Receiver: TRIMBLE NETR9

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Improvement: 0-15%

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Multi-GNSS PPP Analyses

High Latitudes - HOFN (Iceland)

Receiver: LEICA GR25

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<td>0.05</td>
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Improvement: 25-30%
Multi-GNSS PPP Analyses

Low Latitudes - SEYG (Seychelles Islands)

Receiver: TRIMBLE NETR9

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<td>0.05</td>
<td>0.05</td>
<td>0.04</td>
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Improvement: 10-30%
**Convergence Analysis**

- Horizontal Convergence is analyzed with different constellation combinations (G-only, G+R, G+E, G+R+E)

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**Multi-GNSS PPP Analyses**

**GPS-only**: ~2h  
**Multi-GNSS**: ~30 min  

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**GPS-only**: ~2h  
**Multi-GNSS**: ~15 min
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Static-user Scenario

- WTZZ station → Wetzel (Germany)
- Date: 06/09/2016
- 4-7 Galileo Satellites available

WTZZ Galileo-Only PPP

WTZZ GPS-Only PPP

H (RMS): 0.06 m
V (RMS): 0.08 m

H (RMS): 0.04 m
V (RMS): 0.05 m
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Static-user Scenario

- WTZZ station → Wetzel (Germany)
- Date: 06/09/2016
- 4-7 Galileo Satellites available

Galileo-only PPP Studies

WTZZ Galileo-Only PPP

WTZZ GPS-Only PPP

4-7 satellites

>10 satellites

H (RMS): 0.06 m
V (RMS): 0.08 m

H (RMS): 0.04 m
V (RMS): 0.05 m

Comparable Accuracy

4-7 satellites

>10 satellites

H (RMS): 0.06 m
V (RMS): 0.08 m

H (RMS): 0.04 m
V (RMS): 0.05 m

Comparable Accuracy
Galileo-only PPP Studies

Kinematic-User Scenario

- Open-sky scenario
- Urban scenario
Kinematic-User Scenario

- Used receiver: Trimble R10
  - Multi-GNSS receiver
  - Not able to track Galileo Eccentric satellites (E14 and E18)

- Both open-sky and urban conditions are considered
Galileo-only PPP Studies

Galileo-only PPP

- Results Galileo-only (E11, E12, E19, E24) vs GPS-Only

Galileo-only PPP Studies

PPP vs. RTK GPS Only

PPP vs. RTK Galileo Only

Open Sky

Urban

Epoch

North  East

\[ H \text{ (RMS)}: 0.05 \text{ m} \]
\[ V \text{ (RMS)}: 0.10 \text{ m} \]

\[ H \text{ (RMS)}: 0.64 \text{ m} \]
\[ V \text{ (RMS)}: 1.45 \text{ m} \]

\[ H \text{ (RMS)}: 0.67 \text{ m} \]
\[ V \text{ (RMS)}: 0.99 \text{ m} \]

\[ H \text{ (RMS)}: 1.89 \text{ m} \]
\[ V \text{ (RMS)}: 4.01 \text{ m} \]
Galileo-only PPP

Results GPS+Galileo vs GPS-Only

PPP vs. RTK GPS Only

PPP vs. RTK GPS + Galileo

Open Sky

Urban

H (RMS): 0.05 m
V (RMS): 0.10 m

H (RMS): 0.64 m
V (RMS): 1.45 m

H (RMS): 0.04 m
V (RMS): 0.05 m

H (RMS): 0.06 m
V (RMS): 0.12 m

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Galileo-only PPP

- Results GPS+GLONASS vs GPS+Galileo

H (RMS): 0.04 m
V (RMS): 0.07 m

H (RMS): 0.08 m
V (RMS): 0.17 m
CONCLUSIONS

- Galileo is becoming a reality!!

- The introduction of Galileo satellites in the PPP solution significantly improves the performances:
  - Around 20% in open-sky scenarios
  - Dramatic in urban environments

- The performances of Galileo-only PPP solutions are comparable to GPS-only solutions in open-sky scenarios. It is expected to be the same for kinematic scenarios once more Galileo satellites are available.

- In late 2017, it is foreseen to have 22 Galileo satellites orbiting which will represent a major step-forward for PPP.
More about magicPPP

Tomorrow at 10:35:
D5b: Next Generation Sensors in Phones, Tablets and Wearables

Moving forward to the Future Low-Cost PPP Paradigm

Demos at booth 508!!!