Mountain-top Radio Occultation with Multi-GNSS Signals: Experiment and Receiver Signal Processing Techniques

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Outline

1. Objective and Motivation
2. MRO Experiment Description
3. Data Analysis
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Objective and Motivation

**Objective:** Develop robust & accurate GNSS carrier tracking algorithms for RO signals traversing lower troposphere.

**Motivation:** Current technology has limitations
- **Robustness:** Closed-loop cannot maintain lock of signals experiencing strong scintillation
- **Accuracy:** Open loop tracking has large errors.
- **Need:** better understanding of the signal disturbances
Experiment Concept

- Site with minimum clutter, above the Planetary Boundary Layer
- High gain antenna to lift deep fade
- SDR data collection system to enable raw IF data post-processing
April 16-27, 2015: Haleakala (10,023 ft), Maui, Hawaii
Experimental Setup: Electronics and Control

- Limb scan antenna
- Zenith-pointing antenna
Data Collection System Block Diagram

- Dual Polarization Feed
- Wideband Antenna
- PolaRxS Pro
- 3X SDR Front Ends
- Data Recording Server
- PolaRxS Pro RX
- Azimuth Rotator
- Rotator Controller

RF Signal
Frequency Reference
Time Reference
High-Rate Data
Low-Rate Data
Rotator Control

- GPS/QZSS: L1, 1.57542 GHz, 5 MHz
- GLONASS: L1, 1.602 GHz, 25 MHz
- Galileo: E1b/c, 1.57542 GHz, 25 MHz
- BeiDou: B1, 1.56109 GHz, 10 MHz

- GPS/QZSS: L2, 1.2276 GHz, 5 MHz
- GLONASS: L2, 1.246 GHz, 25 MHz
- Galileo: E5b, 1.20714 GHz, 25 MHz
- BeiDou: B2, 1.20714 GHz, 10 MHz

- GPS/QZSS: L5, 1.17645 GHz, 25 MHz
- Galileo: E5a, 1.17645 GHz, 25 MHz
Results: PolaRxS Pro C/N0

04/24/2015  GPS PRN26  Haleakala, HI
Results:
SDR vs. PolaRxS Pro
Troposphere Diffraction Signatures

GPS PRN 30, Haleakala, 4/24/2015, 16:18:29 UTC

Signal Intensity (dB)

Phase (cycle)

Time (s)
Resemblance with Ionospheric Scintillation

Ascension Island - 2013/03/05 Starting at 04:10 UT - PRN25

Time (Seconds)

Raw signal intensity (dB)
Multi-Domain GNSS Receiver Processing

- Adaptive tracking → Parameter optimization
- Inter-frequency aiding → Frequency diversity
- Vector processing → Signal spatial diversity
- Semi-open loop → Temporal diversity
- Open loop → Environment information
- Array processing → Receiver diversity
Adaptive Tracking Algorithms

- State-based framework
- Optimization: MMSE
- Low power + high dynamic signals

Correlator integration time: \( T_{opt} = b_1 \left( \frac{C}{N_0} \right)^{-\mu_1} \)

Filter bandwidth: \( B_{opt} = b_2 \left( \frac{C}{N_0} \right)^{-\mu_2} \)

\( b_1, \mu_1, b_2, \mu_2 \) are functions of receiver hardware qualities and signal dynamics

Adaptive, Conventional, PolaRxS Tracking

Haleakala, GPS PRN 26, L5Q, 4/24/2015, UTC 12:26

Satellite elevation

C/N0 (dB-Hz)

Adaptive PLL
Conventional PLL
Commercial

10dB

400s

1
Ocean Surface Reflection Signatures
Planetary Boundary Layer Height Detection

- Tangent height (km)
  - 35
  - 30
  - 25
  - 20
  - 15
  - 10
  - 5
  - 0
- Refractivity gradient (N-unit/km)
  - -400
  - -300
  - -200
  - -100
  - 0
  - 100

- C/N_0 (dB-Hz)
  - 70
  - 60
  - 50
  - 40
  - 30
  - 20
  - 10
  - 0

- Time (s)
  - 3000
  - 2500
  - 2000
  - 1500
  - 1000
  - 500
  - 0

- Elevation (deg)
  - 6
  - 4
  - 2
  - 0
  - -2
  - -4
  - -6

- Symbols:
  - Green: GPSL1
  - Red: GPSL2
  - Blue: GPSL5
  - Black: threshold
  - Purple: elevation

- Coordinates:
  - 1.9 km, -362 N-unit/km
Conclusions

• MRO experiment: 15TB multi-GNSS IF data in April 2015.
• High gain antenna ~18dB gain, wrong RF front end setting ~11dB loss: net ~7dB gain.
• Adaptive carrier tracking lasted 400s longer than PolaRxS: even with 11dB loss
• Ocean surface reflection signature matches simulation
• PBLH detection validation with local weather station measurements and COSMIC RO results.
• 2nd MRO experiment conducted in May 2017. Dual polarization data collected. 7 dB horn & 18 dB dish. Processing/analysis underway.
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