Constellation Design and Antenna Array Processing for GNSS Radio Occultation Mission

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Introduction

- Based on existing success of the FORMOSAT-3 GPS radio occultation mission, NSPO/NOAA is planning for the follow-on FORMOSAT-7 mission.

- A key design requirement of the FORMOSAT-7 mission is the spatial and temporal distribution of GNSS RO profiles.
  - Uniform distribution → Global weather forecasting and space weather monitoring
  - Local and concentrated distribution → Severe weather forecasting

- The achievement of global distribution with local emphasis poses some challenges to the FORMOSAT-7 constellation design and satellite design.
GNSS RO Events

- The GNSS RO events depend on the following parameters
  - GNSS constellations
    - GPS + Galileo + GLONASS + Beidou
    - Additional signals of opportunity: RNSS and SBAS
    - Number of satellites, orbital parameters
  - LEO observing satellite (FORMOSAT-7) constellation
    - Orbital and constellation parameters
  - Satellite design
    - Satellite pointing
    - Antenna beam
    - Receiver design
  - Others
An analysis tool is developed to facilitate GNSS RO analyses.

- Simulation of multiple GNSS, RNSS, and SBAS
  - GPS, Galileo, GLONASS, Beidou
  - QZSS, IRNSS
  - MSAS, WAAS, EGNOS, GAGAN
- Simulation of LEO satellite
  - Different constellations
- Determination of RO events
- Analysis of RO data distributions
- Optimization of constellation parameters
  - Genetic algorithm
The RO events are analyzed based on the FORMOSAT-7 baseline constellation design.

- Six satellites at 520 km altitude, low inclination (24 deg) and the orbital plane separated by 60 deg.
- Six satellites at 800 km altitude, high inclination (72 deg) and separated by 30 deg.
GNSS Radio Occultation

RO Sounding from GPS within 24hrs

- 1st Launch
- 2nd Launch
SBAS Radio Occultation

RO sounding from SBASs within 24hrs

1st Launch
2nd Launch
QZSS Radio Occultation
Satellite Control

- Through the use of antenna beam slewing and/or satellite attitude control, additional GNSS RO events can be scheduled.
- The satellites are controlled to acquire GNSS RO data when the RO events take place in the interested area.
  - Will not affect the global uniformity
Antenna Array Beamforming

- The primary goal of antenna array beamforming is to enhance the carrier-to-noise ratio of desired signal.
  - An adaptive beamforming algorithm, Minimum Variance Distortion Response (MVDR) algorithm, is implemented to adaptively maximize signal power.
  - Two types of antenna array configurations are considered.
Space-Time Adaptive Processing (STAP)

- Use space (multi-antenna) and time (multi-tap) to make the composite signal.
- The weights are computed by the adaptive algorithm.
- Make one composite signal for selected satellite.
Beamforming Experiment 1

- Antenna configuration 1
Beamforming Experiment 2

- Antenna configuration 2
Conclusions

- Balancing the needs of uniformity in global data distribution and fine resolution in local area may be competing and conflicting.
  - Constellation design: uniform distribution in time and space
  - Satellite control: fine resolution in specified time and space.
- Through the introduction of special satellite operating mode, the RO events in the interested area can be increased in the threat of severe weather.
  - Minimal impacts to the system
- An adaptive beamforming algorithm is implemented to adaptively maximize signal power for the RO weak signal reception.
  - Minimum Variance Distortion Response (MVDR) algorithm
  - Two types of antenna array configurations