Initial Results of the Software-driven Navigation for Station Experiment

(t,r,v)_{ISS}

MAPS Navigation Packet + Pseudolite Signal

Packet Time of Flight and Pseudorange

Estimated Position and Velocity of Ground Node

ISS

SCaN Testbed

MAPS Ground Node

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Demonstration of Software-based navigation methods for MAPS packets are transmitted to ground via ISS telemetry, direct-TDRs link and direct-to-ground from SDR Testbed. Pseudolite signals also being transmitted direct-to-ground via SDR Testbed. MAPS ground node will receive and parse direct signals while connected at GRC to local ground station antenna.
Development and Testing

- Implemented MAPS library within cFE architecture on cubesat flatsat (Linux on Xiphos Q7)
- Ported MAPS library core functions to SDR Testbed Avionics (VxWorks on PPC)
- Verification on Ground Interface Unit prior to launch
- Calibration with ground hardware for baseline timing uncertainty
Flight Operations

- Passes exercise variety of communication networks
- Longer baseline to TDRS for navigation performance assessment
- ISS telemetry implementation represents quickest path to integration
- Direct to ground has lowest network latency, but shortest range
Direct to Ground

- Demonstrate ranging with minimal network latency and infrastructure
- Used NEN-compatible waveform
- Utilized ground receivers at GRC to demodulate signal and decode packets
- Packets timestamped at time of arrival
  - Raw RF also recorded for later processing/integration
- See significant latency in clocks between onboard and ground
  - Limitation of onboard clock synchronization process and inter-hardware timing
  - Using truth data to calibrate truth latency and capture performance due to in-run stability
Extended Baseline Navigation

- Transmissions through TDRS and ISS telemetry paths
- Longer baseline due to high TDRS altitude
- During direct TDRS passes, ISS often provided its telemetry over multiple TDRS elements independently
- See varying latency between TDRS satellites
  - dependent on ground station infrastructure
  - Mostly stable signal but with some outliers
- Assessing latency per satellites per pass
Pseudolite Demonstration

- Waveform implemented by GRC for S-band transmission
- Used PRN 35 to initialize Gold Code
- Synchronization command to sync phase to start of onboard second
- Recorded raw RF for all phases using ground SDR
- Was able to achieve lock during events
- Continuing to develop receiver to process raw measurements
- Forward efforts to implement embeddable signal transmitter and receiver
Summary and Future Work

- Captured over 12 hours of observations
- Demonstrated MAPS software integrated into orbital platform
- Next Steps:
  - Continue to evaluate navigation capability
  - Integrate with post-processed “truth” data
  - Implement calibration processing
  - Test navigation algorithms on received data
  - Mimic test setup in HWIL to continue to run hardware testing
  - Complete ground-based PL transmitter and receiver for continued testing

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From First MAPS Node Onward
SCaN Testbed (GRC)

• Platform developed and operated by SCaN out of Glenn Research Center
• Incorporates multiple SDR elements
  – L-band, S-Band, KA-band
• Broad experimenter platform
  – High bandwidth encoding algorithms
  – Ka-band checkouts with TDRS
  – GNSS software receiver testing
  – Cognitive Networking
• Dedicated Experimenter Interface software layer
• Ground and development units accessible for testing and integration
Multi-spacecraft Autonomous Positioning System

- **Inspirations and Basis:**
  - Increased use of data relays in inter-spacecraft communications (i.e. MRO/MAVEN)
  - Use of Delay and Disruption Tolerant Networking principles to improve communication efficiency
  - Utilization of onboard state propagation models and state estimation algorithms to track current position

- **New Element:**
  - Embed navigation headers in communication packets into frequent inter-spacecraft links as part of evolving data network

- **Enables:**
  - Autonomous onboard Earth-independent navigation capabilities
  - Reduces dependence on Earth-based assets
  - Frees resources on taxed systems (i.e. DSN)
  - Improves state estimation capability with expanding network and increased spacecraft participation

Embedding navigation headers into communication packets works with existing infrastructure, tailored to match onboard capability, and provides expanding navigation network.