NAVIGATION ARCHITECTURE FOR A SPACE MOBILE NETWORK

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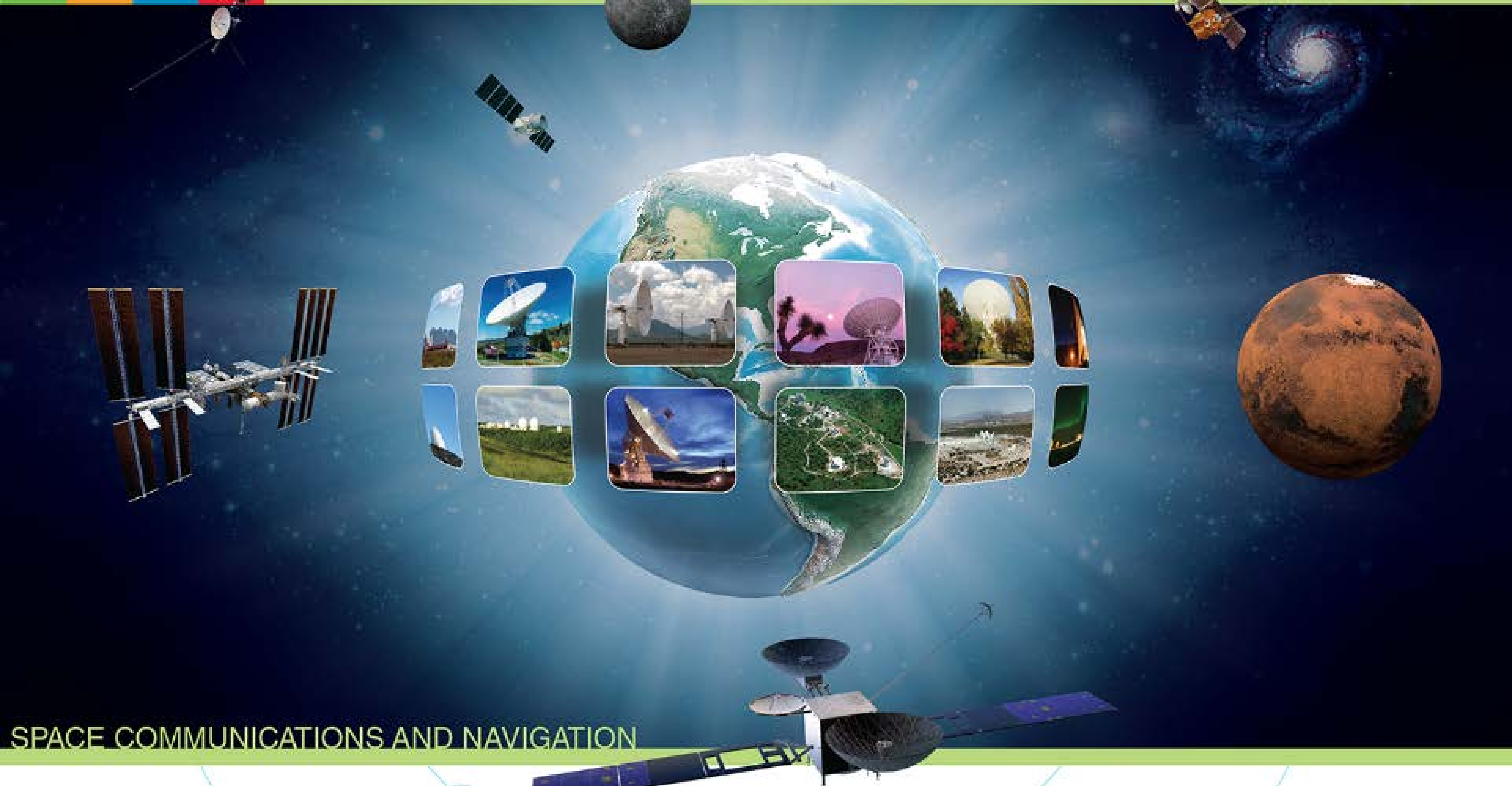

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Outline

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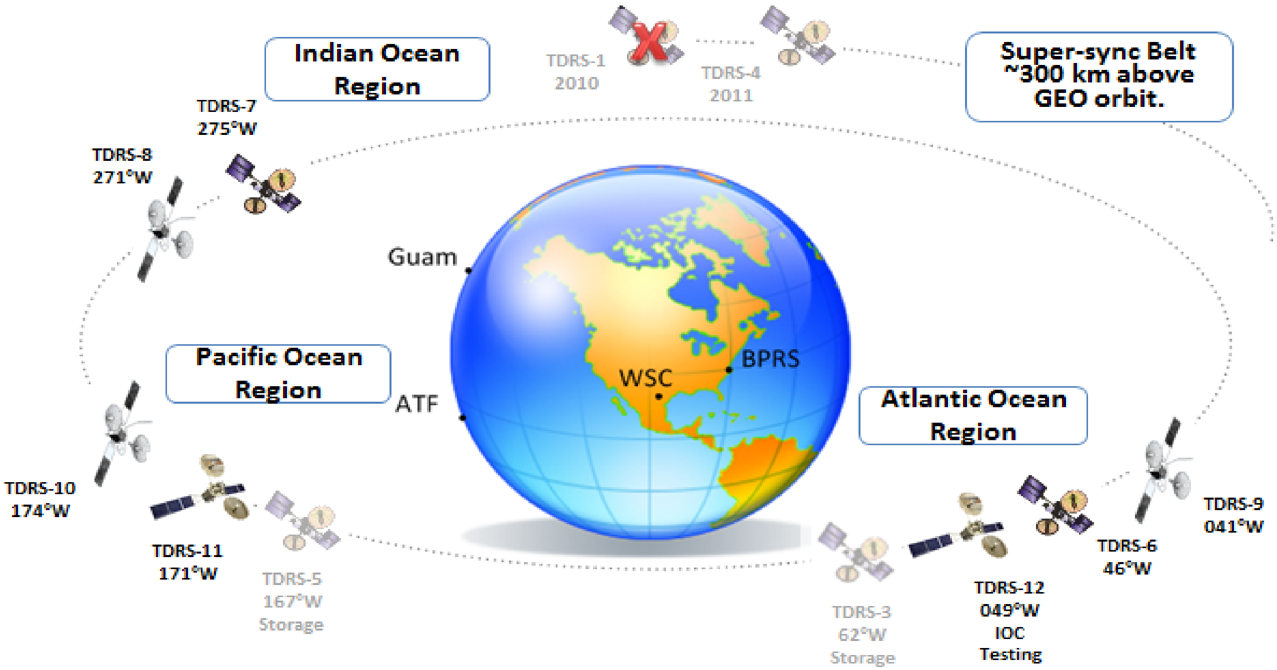
- TASS and the Space Mobile Network
- Navigation Analysis
- Summary

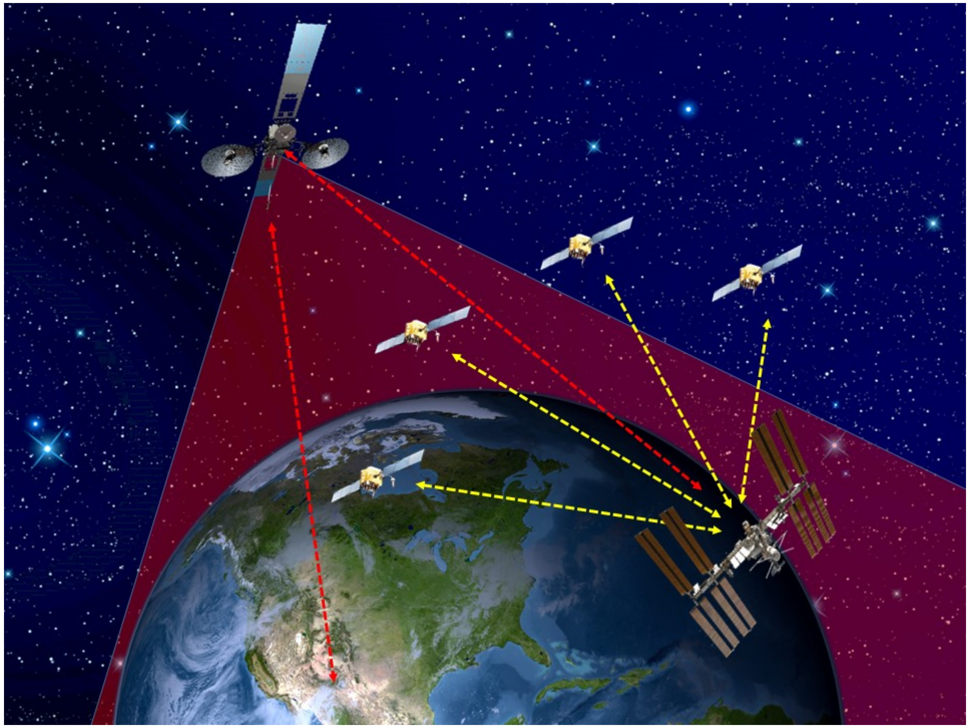
Objectives



- Current: Space communications achieved through ground terminals and the Tracking and Data Relay Satellite System (TDRSS)
  - Requires service scheduling by Mission Operations Centers (MOCs) days in advance
  - Few spacecraft perform autonomous, on-board navigation
- Improved, future network
  - Enables user-hailed services that are autonomously scheduled by the network
  - Provides spacecraft with radiometrics and data to support autonomous, on-board navigation
  - Expands service volume

TASS Overview

- The TDRSS Augmentation Service for Satellites (TASS) provides unique signals and data to *enable autonomous onboard navigation and enhance user operations*
- TASS consists of:
  - Global coverage via TDRS Beacon
  - Multiple Access (MA) fast forward user commanding
  - PN ranging code synchronized with GPS time for one-way forward Doppler and ranging
  - TDRS ephemerides and maneuver windows
  - Global differential GPS corrections and GPS integrity (GDGPS)
  - Earth orientation parameters
  - Space environment/weather data and alerts
    - Ionosphere, Kp index for drag, Effects of Solar Flares/CMEs



TASS has direct benefits in the following areas:

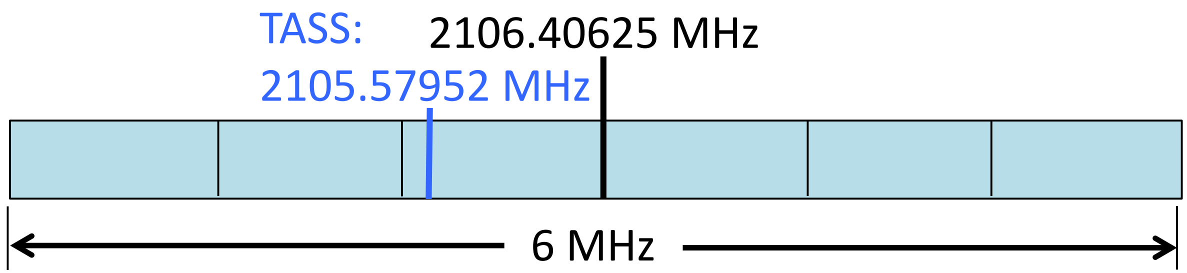
- Science/payload missions
- SCaN/Network operations
- TDRSS performance
- GPS and TDRSS onboard navigation users
- Conjunction Assessment Risk Analysis
- Capabilities consistent with the modern GNSS architecture

TASS and the Space Mobile Network

- Proposed Space Mobile Network (SMN)
  - Similar to the architectural concepts that enable today's terrestrial wireless networks
  - Provides automated delivery of communication services and always available positioning and navigation capability
  - User-hailing paradigm:
    - Spacecraft ("users") autonomously request a communications link from the network
    - Network autonomously schedules comm. link, considering relative locations of user and network nodes
- TASS support of user-hailing
  - Beacon concept allows access to any spacecraft within the service volume
  - Signal structure allows radiometrics (range and Doppler measurements)
  - TDRS Ephemerides and Maneuver Windows provide relay location and integrity
- Additional benefits of TASS
  - Data to supplement and improve on-board navigation (e.g., EOPs, TEC, Kp index, DGPS)
  - Forward Commanding
  - Space weather

TASS Signal Features

- MAF band, offset 826730 Hz @ 2.105579520 GHz



- PN Code: PN_S 1023 bits; PN_L 16368 bits
- PN Chipping rate: 2.095104 Mcps
  - 128 PN_L sequences/one second
  - 2048 PN_S sequences/one second
- 10:1 power ratio on I and Q channels (Q is a dataless pilot)
- 1024 bps data message in frame structure
- 10 seconds to broadcast entire message, but flexible

Navigation Analysis: Two TASS User Classes

- Analysis of TASS-based navigation
  - Intended to study feasibility of TASS-based navigation in terms of service access (i.e., visibility); measurement settings relaxed
  - Linear covariance analysis using an extended Kalman filter (EKF)
  - Measurements: pseudorange and Doppler from the TASS beacons

TESS Spacecraft

- Network user types evaluated:
  1. First step to SMN: Disadvantaged LEO, low SWaP, no GPS receiver, possible lights-out operations (e.g. cubesat) – within current network service volume
  2. Future: High altitude, always above GPS constellation, sparse GPS signal environment (e.g. TESS) – user class that would be added to network under augmented TASS service

Navigation Analysis: Assumptions in Study

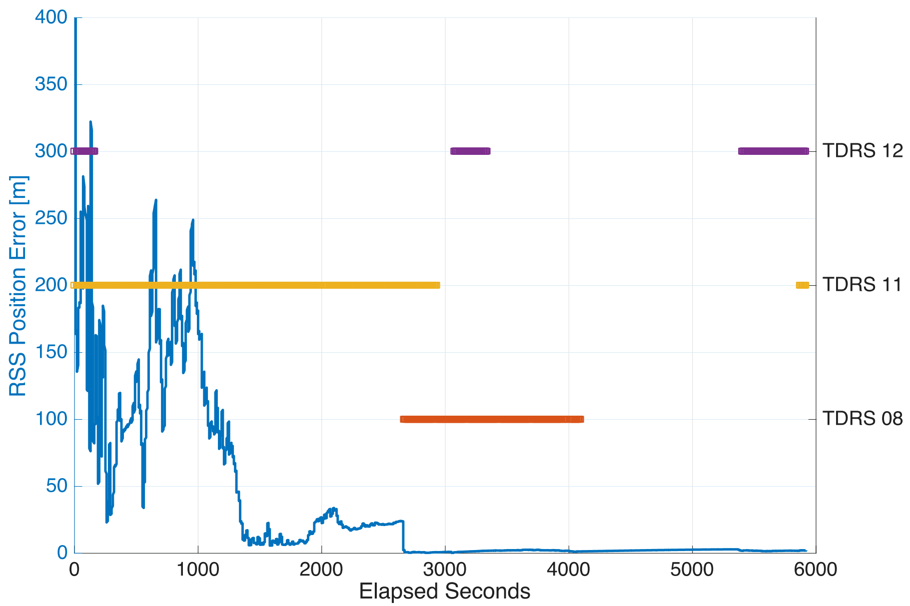
- TASS Beacon disseminators
  - LEO case (polar orbit): three TDRS, one at each of the existing GEO nodes
  - TESS-like case (lunar resonance orbit): three TDRS + four ground stations

	Orientation	Beam	EIRP @ Boresight
TDRS Beacons	nadir-pointing	conical, global coverage + 1400 km annulus	36 dBW
Ground Beacons	zenith-pointing	Conical, 30° or 55° or 80° beamwidth half-angle	72 dBW

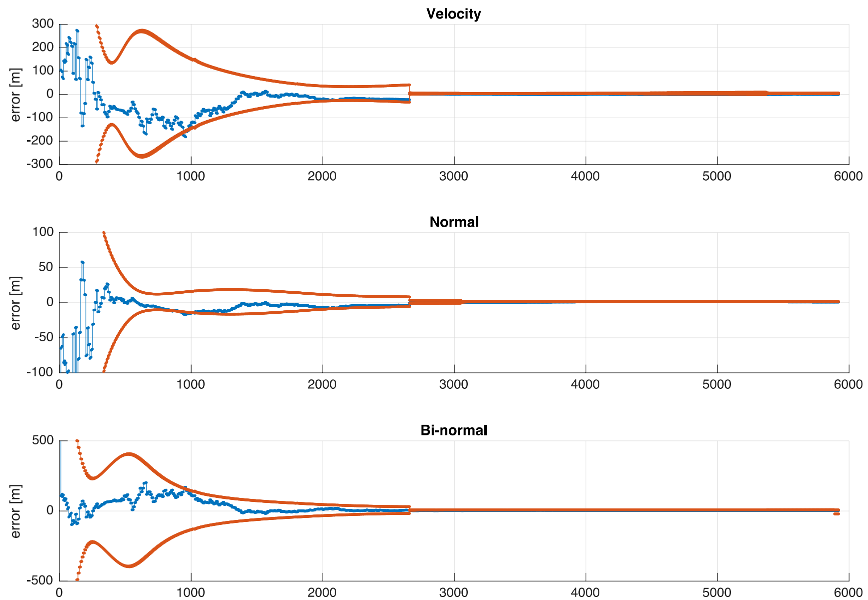
- State
  - Position and Velocity
  - Clock bias and bias rate
- Measurement/filter settings
  - Meas. noise covariance: $1 m^2$ pseudorange and $1 cm^2/s^2$ Doppler
  - Meas. updates: 10 s for LEO case, 30 s for TESS-like case
  - Initial state covariance: $100\ km^2$ position, $1\ cm^2/s^2$ velocity

Navigation Analysis: LEO Study Case

- Tracking & full demodulation of data message over 1 orbit
- Minimum Eb/No: 31.8 dB-Hz; Receiver: 35 dB-Hz (3dB margin)



RSS Position Error and Visibility



True and Formal 3σ VNB Position Errors

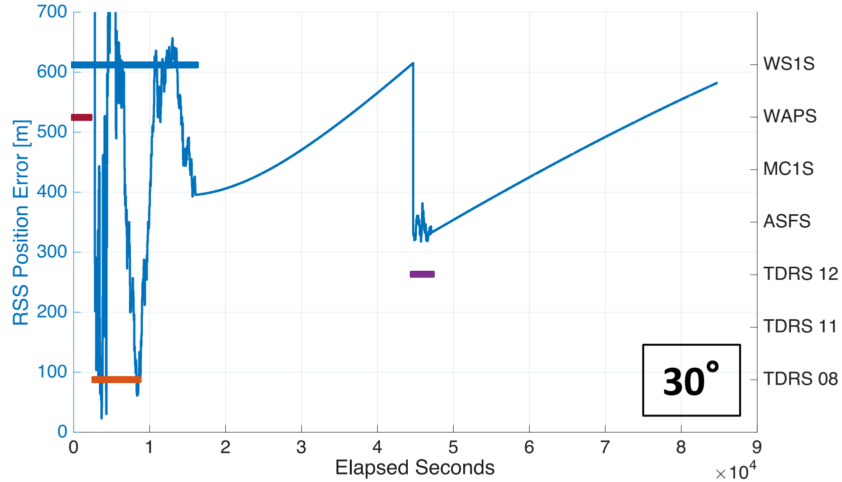
- RSS error profile indicates the beacon would adequately support a LEO user in a polar orbit
- Filter convergence indicates sufficient beacon visibility (not expected positioning accuracy)

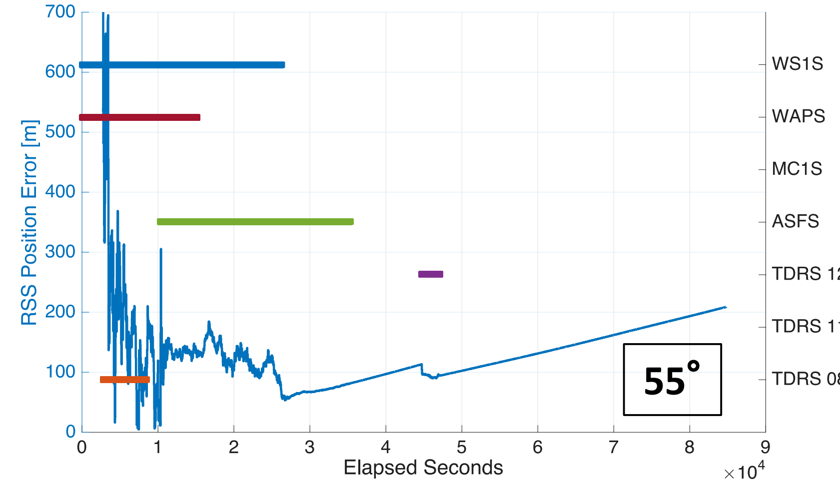
Navigation Analysis: Lunar Resonance Orbit (17x59RE, TESS) Case

- Evaluated 1 day out of 14-day orbit period
- TDRS-based beacons: Tracking only, using dataless Q channel (26 dBW EIRP at boresight)
  - 1 s integration time, receiver acq/trk threshold: 5 dB-Hz
- Ground station beacons: full demodulation of data message (72 dB EIRP at boresight)
  - 20 ms integration time (as in LEO case), receiver threshold: 35 dB-Hz
  - 4 sites from current Near Earth Network (Alaska, McMurdo, Wallops, White Sands)
  - Provides tracking, TDRS ephemerides, and other data

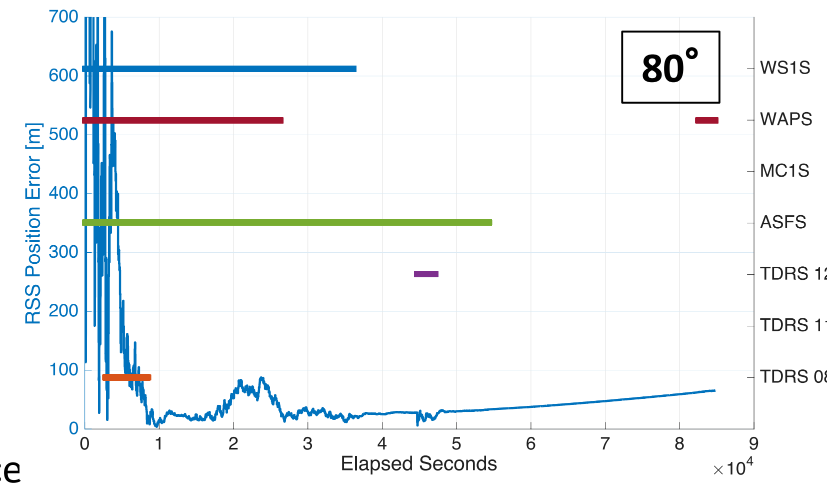
Navigation Analysis: Lunar Resonance Orbit (17x59RE, TESS) Case

TESS-like user position error and visibility for TASS Pseudorange and Doppler





- RSS profiles indicate this TASS beacon configuration would support a user in a lunar resonance orbit during the interval studied
- Augmentation of network is essential
  - 71 dBW EIRP sufficient but beamwidths below 55° significantly degrades performance



Summary

- TASS concept builds on existing and forthcoming SN services to provide network efficiency by structuring user data to provide navigation parameters
- TASS is a key enabler of the next generation network
  - Provides information mandatory for acquisition at both service terminals
  - Reduces need for traditional, pre-scheduled services
- A 3-node GEO relay network is minimally sufficient for LEO; augmentation allows TASS to serve higher earth regime users
  - Augmentation by NEN beacons demonstrated here, other possibilities include employing omnidirectional/backside relay beacons or placing beacons in other orbits
- TASS data message supports high accuracy on-board nav (EOPs, TEC, Kp index, GDGPS)

BACKUP

TASS Features That Benefit Nav.

Table 1. TASS Features That Aid or Enable Navigation

FEATURE	SIGNIFICANCE
Signal Structure	Correlated PN chipping rate, frequency selection, and message framing provide means for measuring pseudorange and Doppler, and determining time. Useful as independent standalone observation inputs to orbit estimation or supplements to GPS observations. TASS reduces need for user to request "tracking-only" network services.
TDRS Ephemerides	High accuracy relay orbit knowledge provided by TASS improves user orbit estimation, provides a means of identifying relay direction for user antenna pointing and improves relay pointing error for high frequency services. TASS signal received by worldwide distributed receivers provide metric tracking observations of the relay that improve ephemeris accuracy and reduce the time to recover after a maneuver.
TDRS Maneuver Window	A user applies the TDRS maneuver window knowledge to edit tracking measurements from a maneuvering TDRS or accommodates the maneuver in their orbit estimation process. Reduces ground intervention for uploading TDRS maneuver windows.
Earth Orientation Parameters	Users require updated Earth Orientation Parameters (EOP) to perform coordinate system transformations. The frequency of EOP updates relate directly to the navigation solution accuracy of the user platform.
Total Electron Content	The Total Electron Content (TEC) allows users to correct for disturbances in transit time and frequency change introduced as the reference signal traverses the ionosphere. TEC provides information for Earth observing science instruments.
Kp Geomagnetic Index	The Kp index directly impacts the drag force on a LEO user, which is one of the largest sources of inaccuracy in orbit knowledge.[7, 8] TASS includes a timely update of the 3-hour Kp index to aid definitive and predictive orbit estimation.
GPS Differential Corrections	GPS differential corrections enable precise, real-time navigation for a variety of applications including Earth science, formation flying, and atmospheric sensing.
GPS and TDRS Integrity	Integrity information on the networks that source tracking data, alerts users to potentially degraded measurements that may affect navigation performance.

Additional TASS Benefits

Table 2. Additional Benefits of TASS Beacon

FEATURE	SIGNIFICANCE
Forward Commanding	Missions benefit from the ability to send commands either impromptu, at specific geo-spatial locations, or at specific times. The forwarding commanding allows users to re-spond to near-real time alerts or dynamic events, coordinate and correlate science obser-vations, provision limited or lights out operations, or inform the user platform of the need to hail for communication services in the SMN. Combined with Demand Access return services, users achieve communication without the burden of scheduling services.
Time Transfer	The signal's rational time base referenced to UTC offers a method independent of GPS to disseminate time and maintain synchronization across the network and user community necessary for the decentralized SMN. Precise synchronization will facilitate the transi-tion from two-way to one-way radiometric techniques.
Direct Science Application	The global and continuous TASS presence provides a signal of opportunity available for Earth remote sensing. The smaller wavelength of the S-band signal, aided by the low phase noise implementation[8,9] enhances the science return from radio occultation and re-flectometry, augmenting climatology analysis.
Space Weather	TASS provides a means to disseminate the broadly used Space Weather alerts to the or-biting community which can then take action to protect humans or sensitive instruments. Alerts include event type, directionality, force, and time of impact for appropriate segre-gation by the user community.

Future Studies

The study “TASS: An Enabling Service for the Space Mobile Network” generated a subset of additional study topics surrounding TASS and onboard navigation in the SMN:

1. SMAF service trade
2. Analysis to define orbit options for relays to service the full near-Earth regime
3. The number of relays providing a TASS beacon and their orbits
4. Autonomous navigation for relays
5. Relay requirements to mitigate impacts of DTN, which include options and analysis for a relay time standard and ability to modulate data onto the beacon at the relay directly
6. Additional users cases to analyze; other orbit regimes, user equipment baselines
7. Orbit estimation error analysis for users based on current analysis
8. Further enhancements and data offerings of a beacon service
9. Analyze the impact of Space Environment on orbit determination

TASS Serves a Spectrum of Users