PNT as a Service (PNTaaS): Leveraging SATCOM for PNT

Dr. Alison Brown
NAVSYS Corporation
14960 Woodcarver Rd, Colorado Springs, CO 80921
www.navsys.com (719) 481-4877
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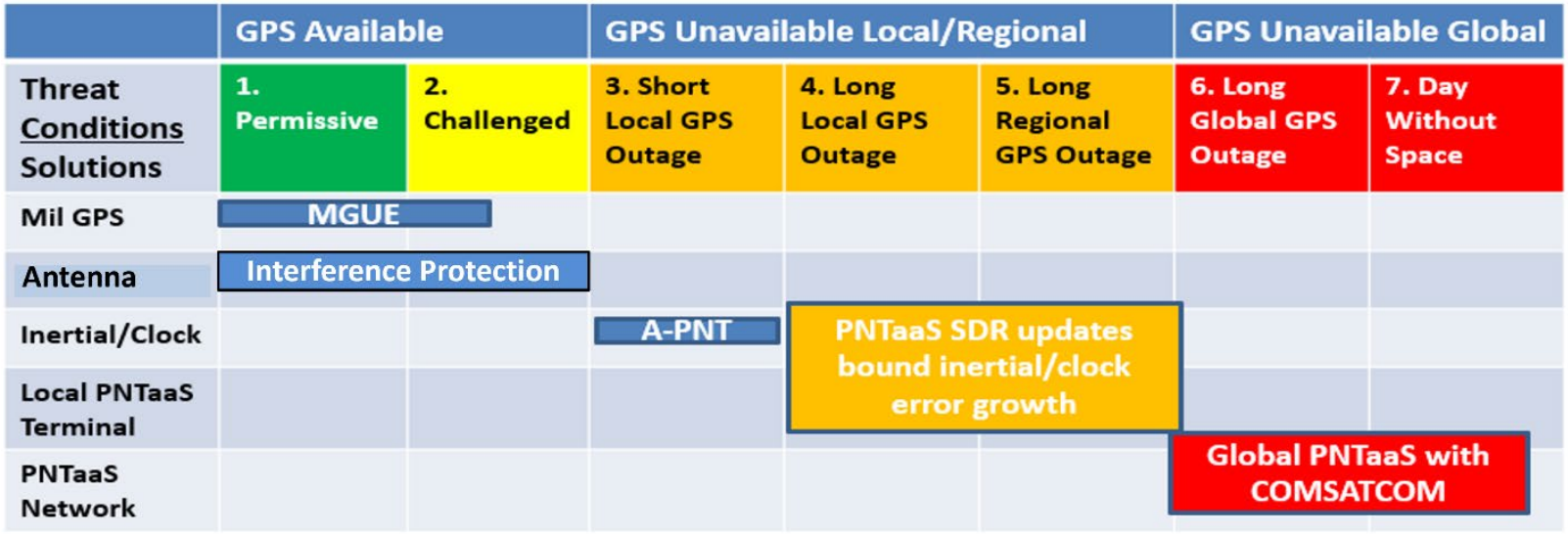
NAVSYS Overview

***MISSION** : To provide **specialized Positioning Navigation and Timing (PNT) products** and **services** for our customers by leveraging our core technologies, unique technical expertise, innovative engineering, strong work ethic, and high standards of excellence.*

- Founded in 1986 by Dr. Alison Brown
- In top 10 companies receiving SBIR awards from DoD in Colorado and have high commercialization success rate for our SBIR projects
- Tibbets Award, Coggins Award, AFEI Award for Enterprise Integration

GPS Risk Levels



Signals of Opportunity (SoOP) provide means to bound inertial and clock error growth in absence of GPS

*A-PNT: Assured Positioning Navigation and Timing

GNSS versus SATCOM Operation

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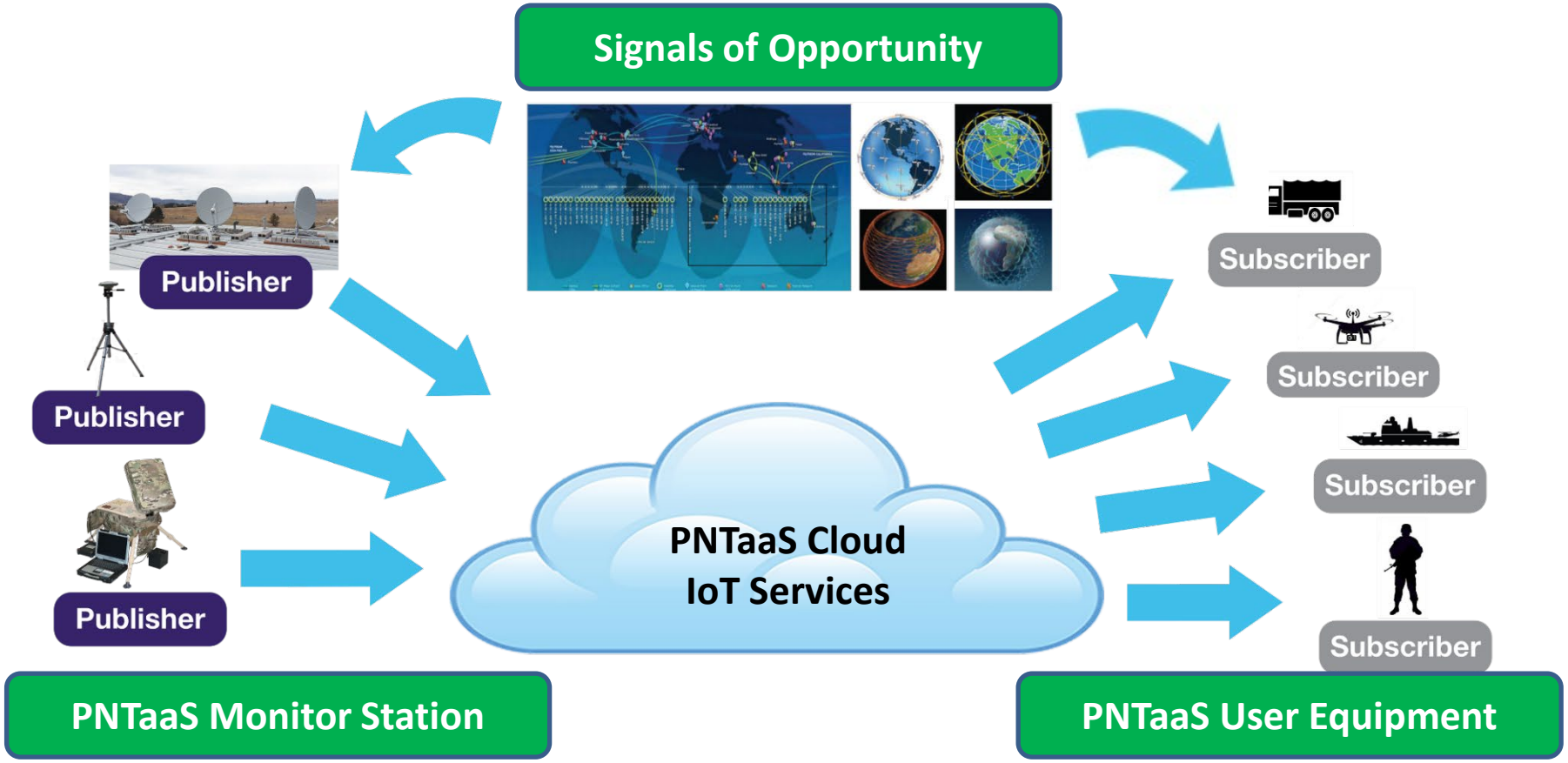
Space Segment	GNSS	SATCOM
Satellite Broadcast Power	L-Band: Pr = -158 dBW	C-band SATCOM: Pr = -159 dBw Ku-band SATCOM: Pr = -161 dBw
Frequencies	Limited allocations for PNT	Extensive COMSATCOM allocations
Signal Bandwidth	24 MHz	C/Ku-Band: 36 MHz
Modulation	PRN codes	Digital data
Time Stamps	Sync to onboard Atomic Clock	Asynchronous onboard
Data Modulation	50-100 bps	Full bandwidth

User Segment	GNSS	SATCOM
Antenna	Omni	Dish or Phased Array
Data Processing	Spread Spectrum provides processing gain and TOA	Modem provides digital data demodulation
Navigation	4 or more observations for PNT	n/a

PNT as a Service (PNTaaS)



GNSS vs PNTaaS

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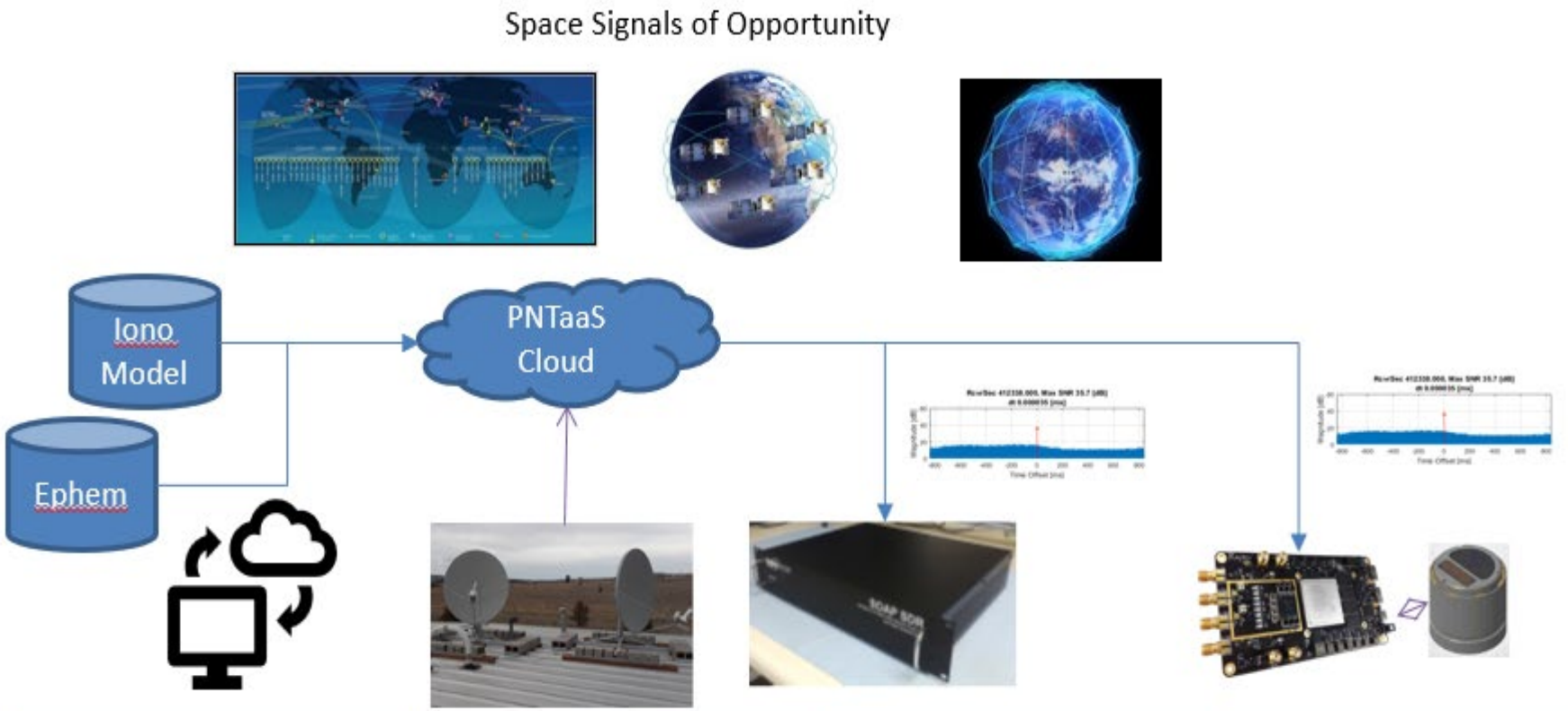
Space Segment	GNSS	PNTaaS
Satellite Broadcast Power	L-Band: Pr = -158 dBW	C-band SATCOM: Pr = -159 dBw Ku-band SATCOM: Pr = -161 dBw
Frequencies	Limited allocations for PNT	Extensive COMSATCOM allocations
Signal Bandwidth	24 MHz	C/Ku-Band: 36 MHz
Modulation	PRN codes	Monitor publishes snapshots
Time Stamps	Sync to onboard Atomic Clock	Monitor publishes TOA of snapshot
Data Modulation	50-100 bps	Network access to PNTaaS data
User Segment	**GNSS**	**PNTaaS**
Antenna	Omni	Multiple Omni at different bands
Data Processing	Spread Spectrum provides processing gain and TOA	Processing gain from PNTaaS snapshot correlation gives TOA
Navigation	4 or more observations for PNT	Sequencing through multiple snapshots provides A-PNT updates

GNSS versus SoOP Signals

Band	Freq	SoOP	Orbit
L	1 – 2 GHz	GNSS, Iridium Inmarsat	MEO GEO
S	2 – 4 GHz	GlobalStar TDRS COSMIC-2	MEO GEO LEO
C	4 – 8 GHz	Xona Intelsat, Telesat, SES, etc.	LEO GEO
X	8 – 12 GHz	WGS, Skynet	GEO
Ku	10.7–12.7 GHz 12 – 18 GHz	OneWeb, SpaceX DBS, Viasat	LEO GEO
Ka	17.8-18.6 GHz	Telesat, Kuiper, O3B ViaSat, Telesat	LEO GEO

Existing SATCOM systems have many more frequency allocations than GNSS

PNTaaS CONOPS



1. PNTaaS Server builds list of available SoOP and publishes SoOP Location data	2. Monitor Station observes SATCOM SoOP with high gain antenna and publishes SoOP Snapshot	3. PNTaaS Reference SDR receive PNTaaS SoOP and publishes TOA relative to Master Clock	4. Remote PNTaaS SDR sets local SoOP Sequence and subscribes to PNTaaS data to provide PR update to inertial & clock A-PNT device

SoOP Open Architecture PNT (SOAP) SDR

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Modular design supports multiple GPS receivers

Time synced fast sequencing supports 100s of SoOP

Currently Supported GPS Devices

NovAtel GPS Receiver | DAGR | uBlox

IMUs

ADIS MEMS IMU

KVH

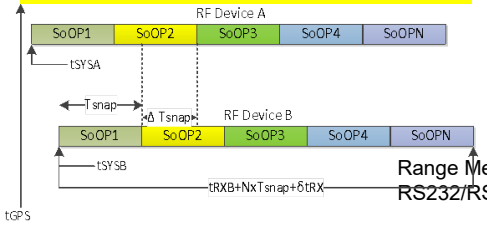
Systron Donner

Honeywell

NG

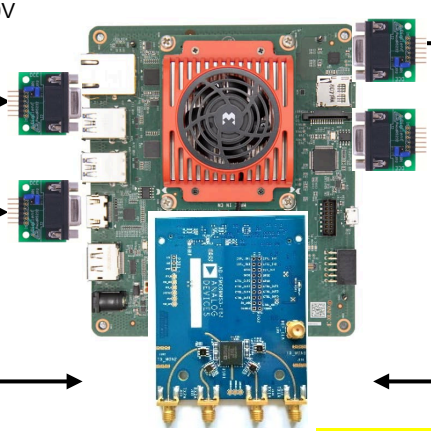
Drivers included for most COTS inertial units

Precise time tags for external aiding sensors



PPS RS232 or 3.3/5.0V

Zynq UltraScale+ 3EG w/ quad ARM CPUs
Analog Devices AD9361 Agile Transceiver



RS232/RS422/RS485

Vehicle Speed RS232/RS422/ USB/Ethernet

Odometer or Velocity

RS232

RS422

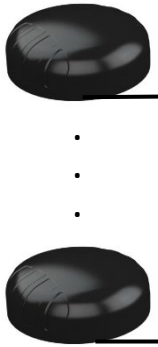
RS485

Range Messages RS232/RS422

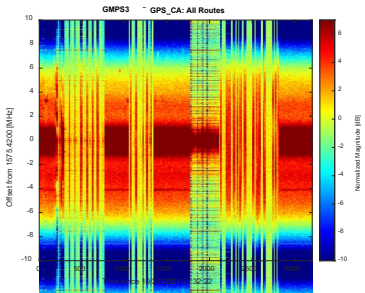
Range Messages USB/Ethernet

Vehicle Speed USB/Ethernet

L/C-band Antenna Array

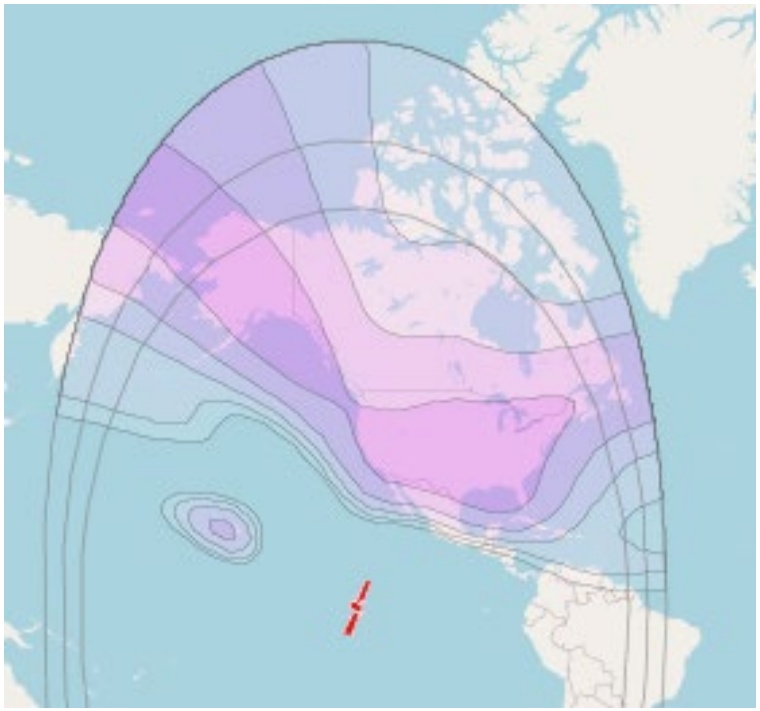


Real-Time FFT for RF SA and ML

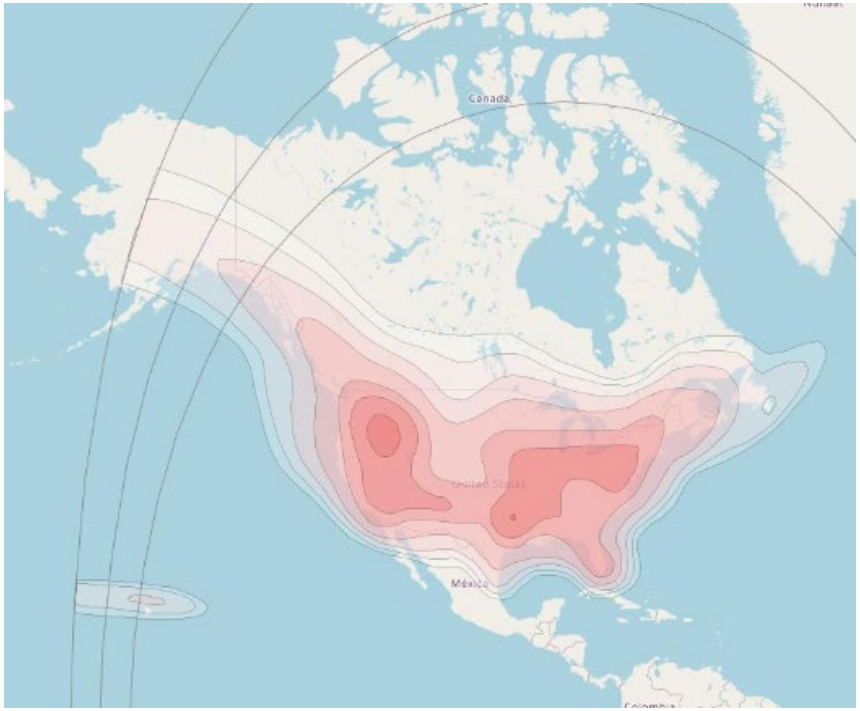


SOAP SDR + InterNav fusion runs on Xilinx SoM

Example GEO SoOP Footprints

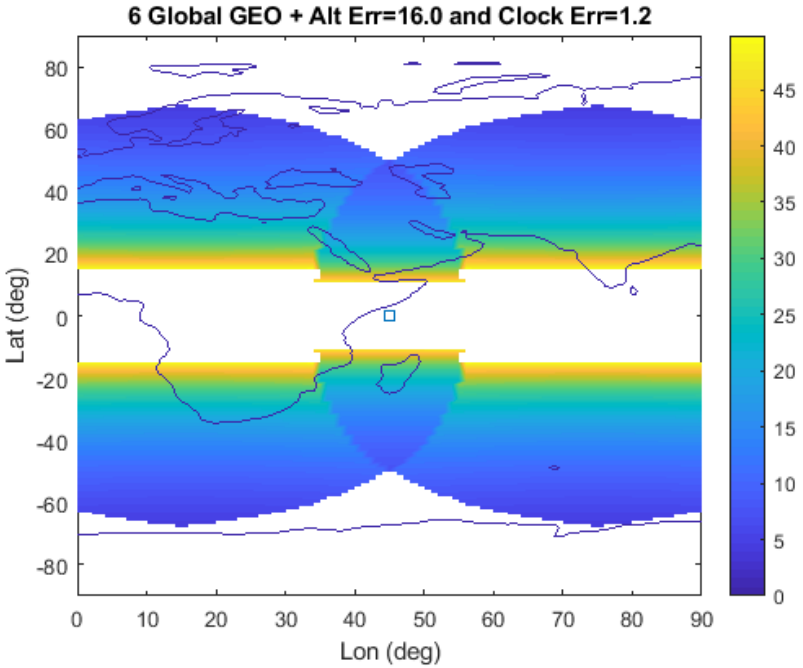


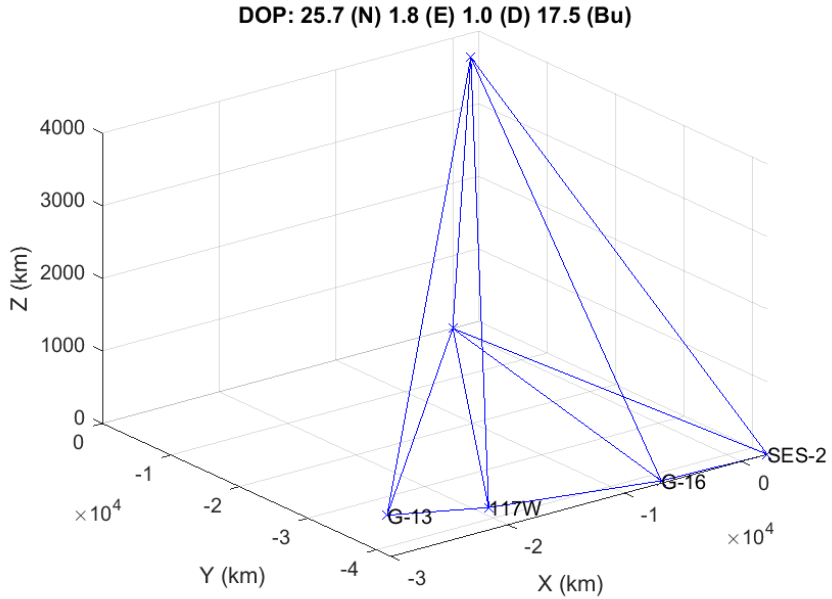
GALAXY-30 (C-Band)
~ 38 dB-Hz C/N0
(20 MHz BW)



SES-2 (Ku-Band)
~ 38 dB-Hz C/N0
(20 MHz BW)

PNTaaS GEO-only Geometry

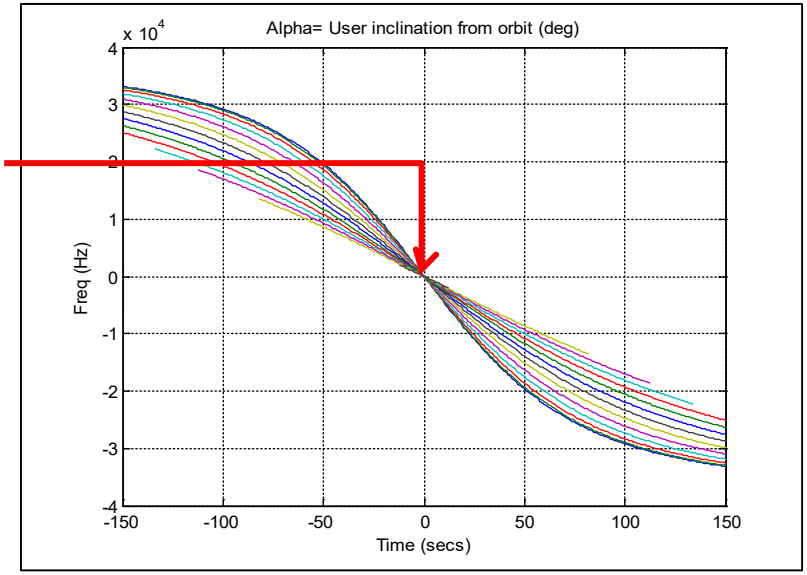


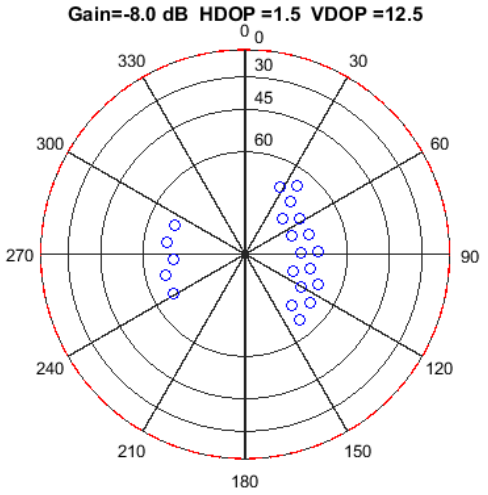


- GEO-only can support PNT with altitude aiding but North/Clock DOP is weaker
- Geometry improves with clock calibration at start & precision clock
- Benefits of GEO SoOP are persistent coverage

LEO PNT Observation Geometry

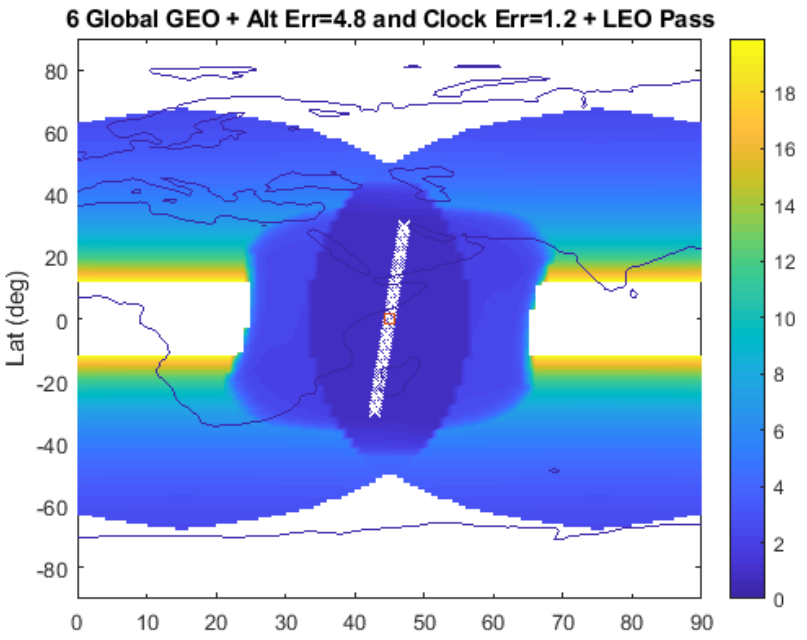
- Doppler tracking of LEO SV “transit” across the sky gives 2DOF
  - Time of closest point in transit (θ)
  - Doppler Rate of change at θ gives declination from orbit (α)
- User’s inertial/clock solution needs 4D geometry to correct PNT offset
  - 2 SV transits (4DOF)
- Example of LEO “Transit” Geometry
  - In 5 minutes => HDOP=1.5 using multi-plane Doppler only updates (e.g. Starlink, OneWeb)
  - TOA from known code adds additional observation (e.g. STL, Xona)

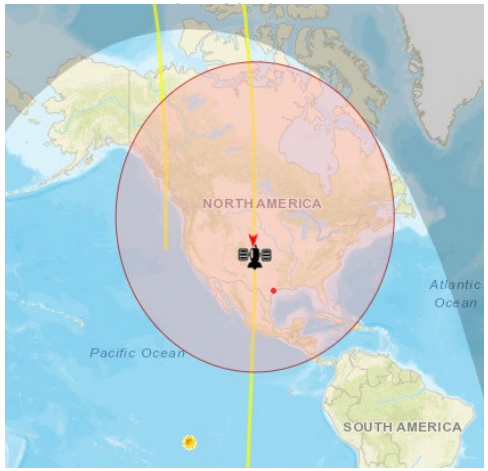




PNTaaS GEO/LEO Geometry

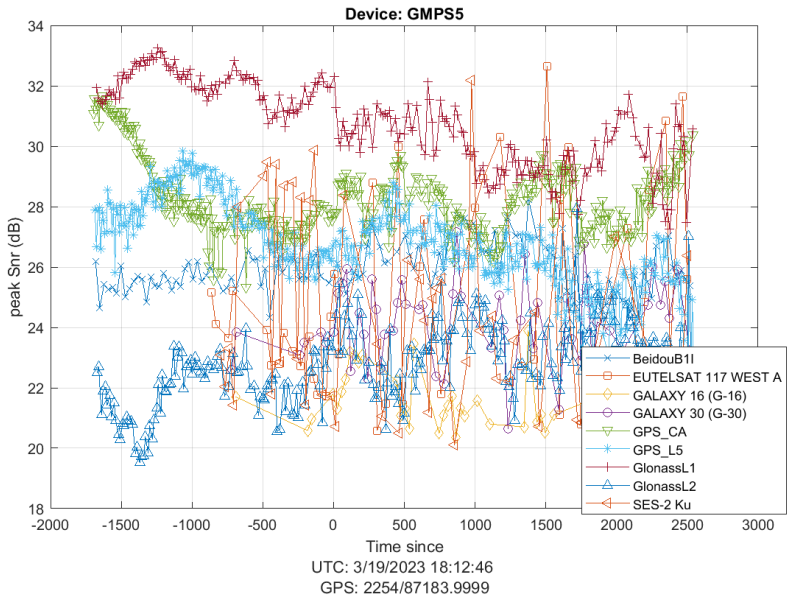
- GEO + occasional LEO pass “transit” will provide 4D geometry
- Benefits are global coverage and periodic clock calibration
- Doppler-only updates are sufficient when have an accurate SDR clock

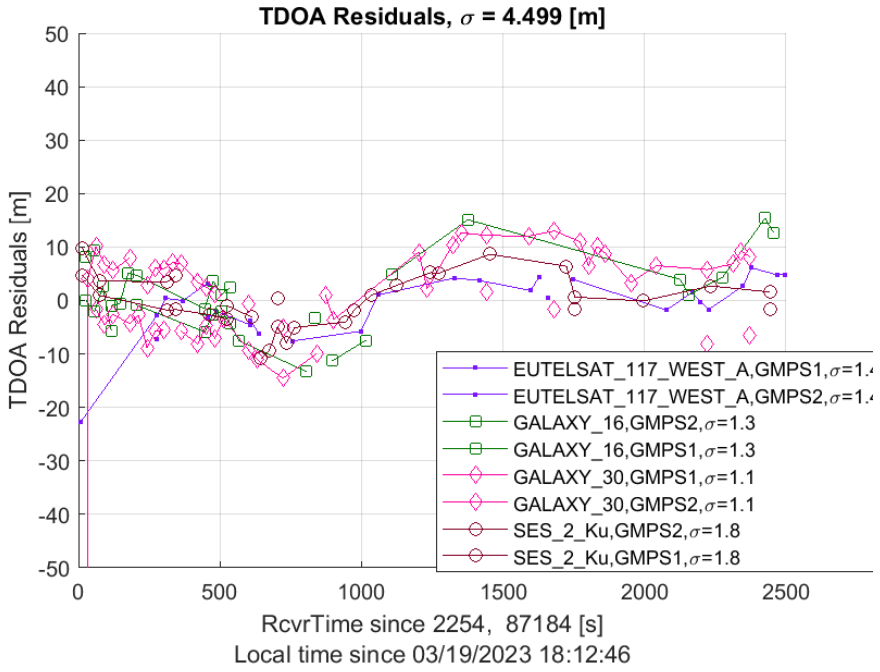




Example OneWeb Footprint (Ku-Band)

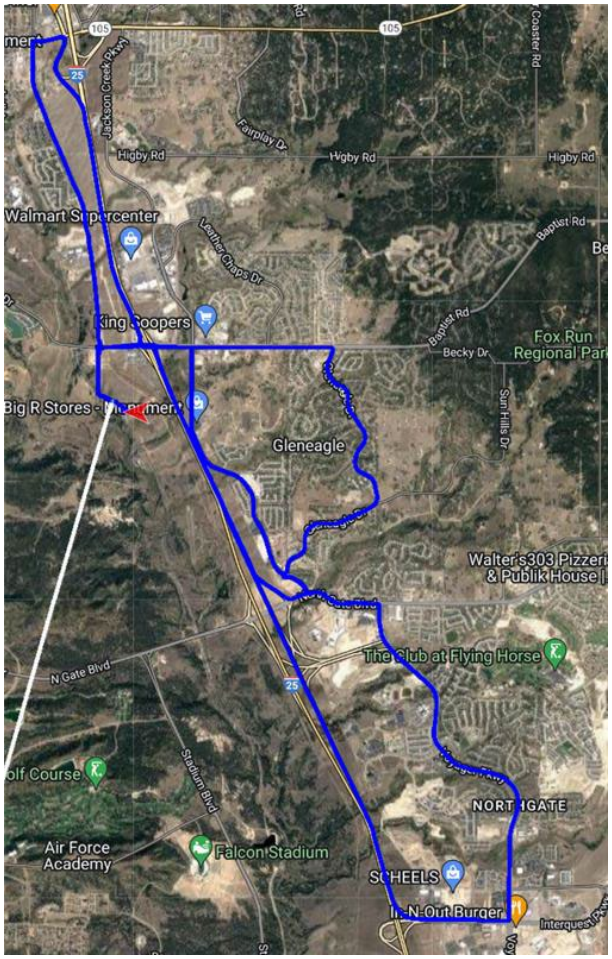
SoOP Snapshot Observations

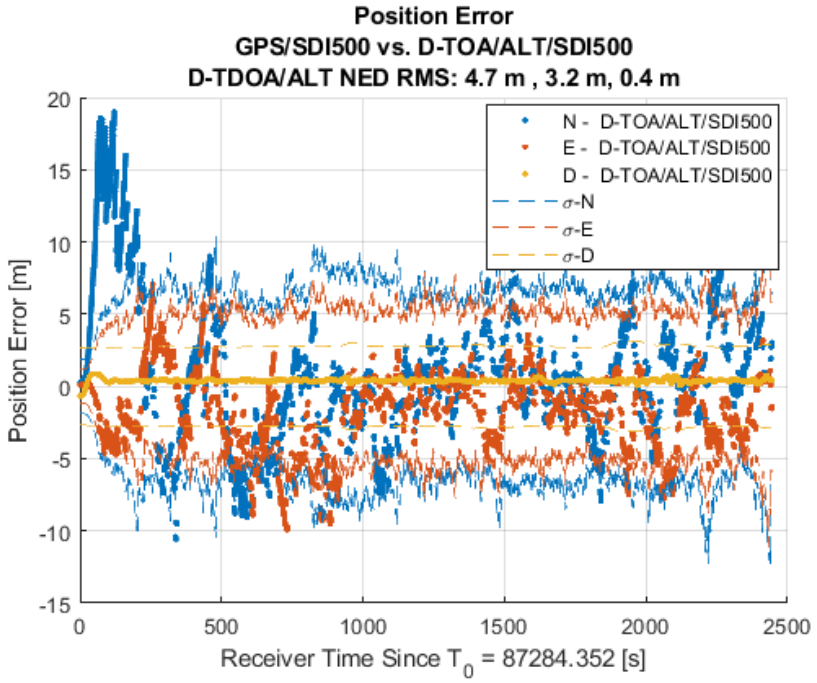




- 85 msec snapshots at 20 Msps
- C-Band: GALAXY 16, GALAXY 20
- Ku-Band: SES-2 EUTELSAT 117

GEO + MEO PNTaaS Results





GEO + Alt only PNTaaS Results

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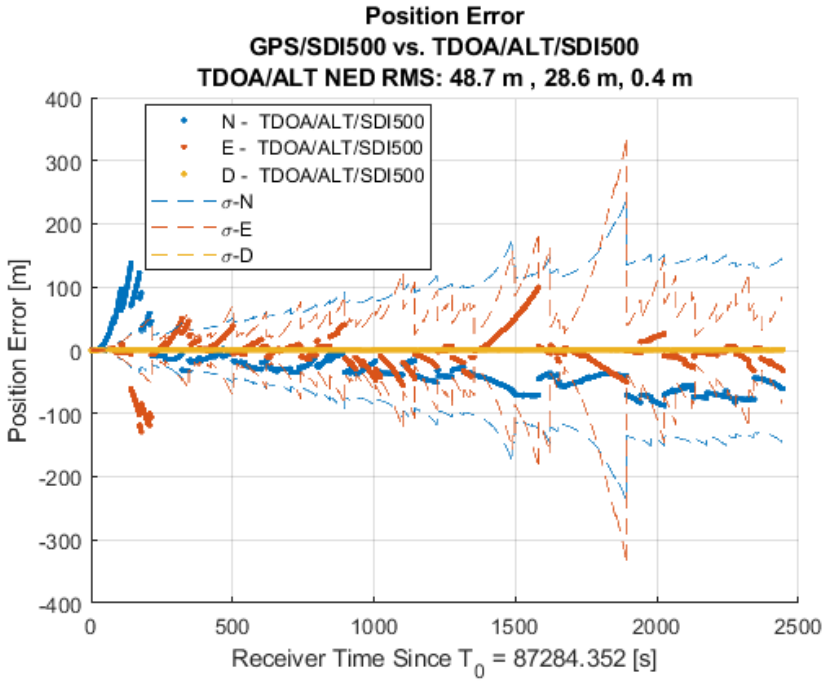
- Accuracy is a function of inertial and clock
  - SDI1500 IMU
  - Wenzel OCXO
  - < 150 meters steady state
- Accuracy would improve with a CSAC
  - ~11 m/hr of drift



PNTaaS Solution Benefits

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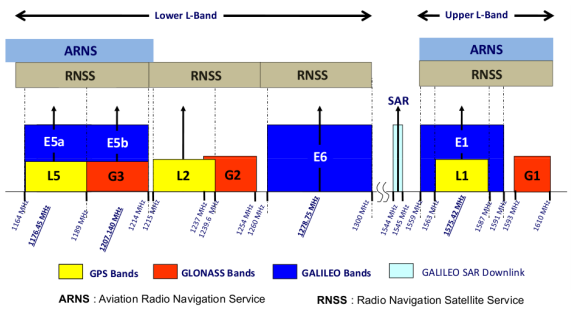

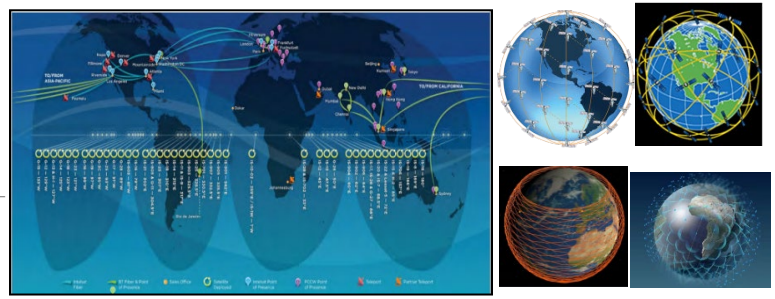

INTELSAT Viasat

SES Government Solutions TELESAT

OneWeb STARLINK

Problem/Opportunity

All GNSS signals are in L-band (1.1-1.6 GHz) and are vulnerable to interference. Delivering Enterprise PNT provides opportunity for a global PNT backup capability services leveraging existing commercial satellite and terrestrial signal sources as SoOP accessing frequency allocations from 3-30 GHz.

Proposed Solution

PNTaaS provides data services to enable use of commercial broadband GEO, MEO and LEO satellite systems as SoOP. Massive constellation size and different frequency ranges provides PNT resilience. Working with commercial partners allows for global delivery of PNTaaS leveraging existing SATCOM constellations and ground infrastructure.

Impact

FCC reports 194 approved GEO satellites and 43 approved NGSO systems with 4,408 satellites from SpaceX, 720 satellites from OneWeb 117 satellites from Telesat, 66 satellites from Iridium, and 42 satellites from O3B with thousands more launches planned.

PNTaaS Commercial Service Components

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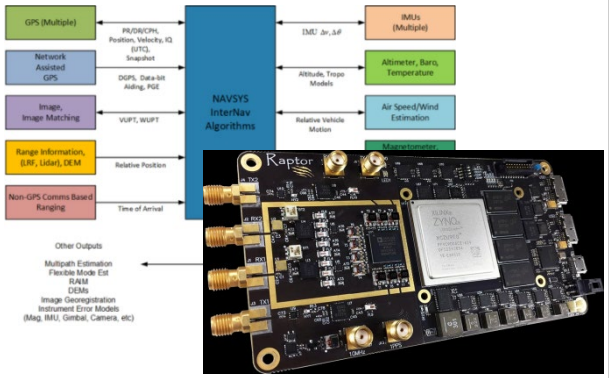
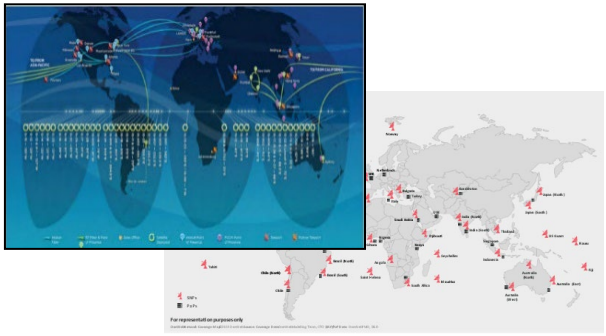
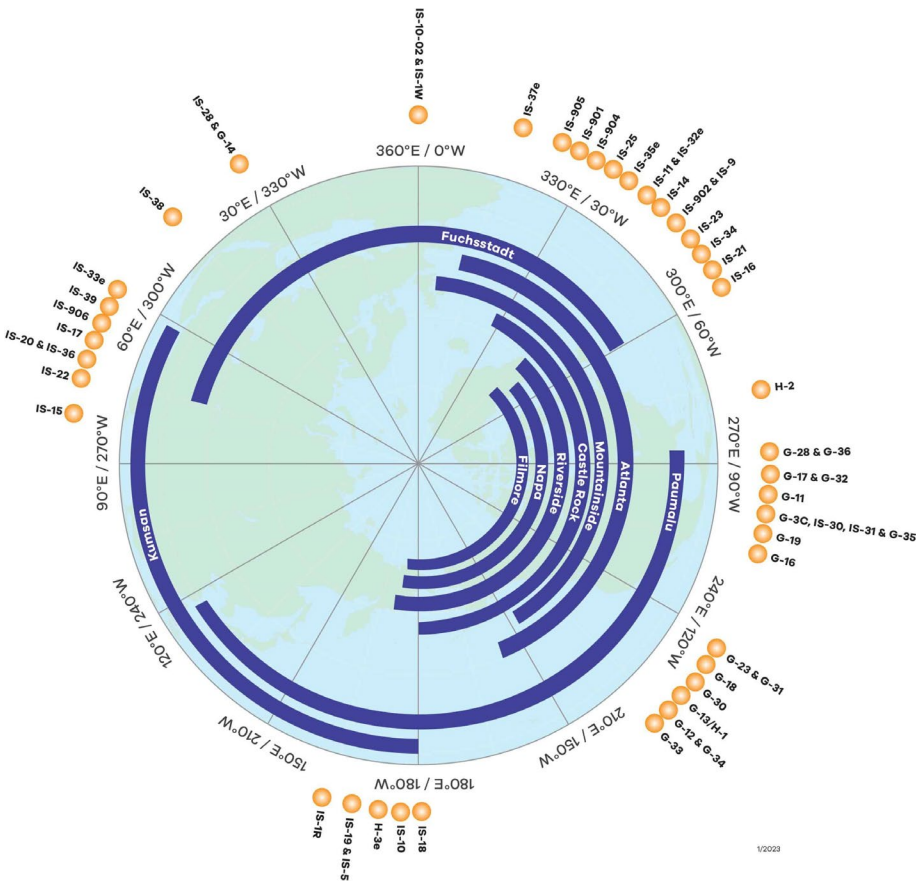
PNTaaS Monitor	SOAP SDR Licenses	Global Deployment
 PNTaaS Monitor Stations	 InterNav A-PNT SW + SOAP SDR	 IntelsatOne , Viasat and OneWeb Global Satellite Network Portals
• PNTaaS Monitor SDRs being sold for deployment and integration into SATCOM ground stations • Compatible with multiple satellite constellations, both GEO and NGSO L, C and Ku-Band frequencies	• NAVSYS has sold over 2,000 A-PNT commercial product licenses (B2B) • SoOP Open Architecture (SOAP) SDR being offered to our customers under license for PNTaaS applications	• NAVSYS is working with multiple SATCOM service providers (GEO and NGSO) to integrate PNTaaS SDRs into their global satellite network portals to offer PNTaaS data for commercial and DoD markets

IntelSatOne Global Network

NAVSYS Corporation



- Castle Rock Teleport

Visible Arc

28°W – 180°W

Intelsat Satellites in the Visible Arc

IS-18 · G-15 · G-12 · G-13 · H-1
G-14 · G-18 · G-16 · G-19 · G-3C
IS-30 · IS-31 · G-25 · G-17 · G-28
IS-21 · IS-34 · IS-25 · IS-23 · IS-1R
IS-14 · IS-11 · IS-32e · IS-35e
G-23 · G-11 · IS-5

OneWeb - by the numbers

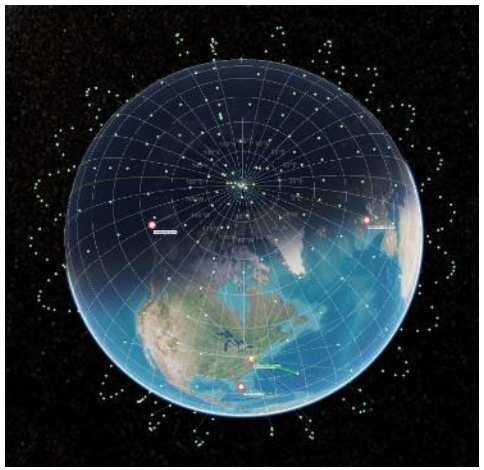
- Constellation is **100% deployed** (618 operational satellites)
- 30 on-orbit spare satellites scheduled to be launched 10 May
- Orbit raising and check-out will continue through **Q3/Q4 CY2023**

Launch #15 (Complete)
Launch Date: 8 December 2022
Launch Site: Florida
Payload: 40 OneWeb Satellites
Launch Vehicle: Falcon 9 (Space X)
Space Vehicles:#s 463-502

Launch #16 (Complete)
Launch Date: 10 January 2023
Launch Site: Florida
Payload: 40 OneWeb Satellites
Launch Vehicle: Falcon 9 (Space X)
Space Vehicles:#s 503-542

Launch #17 (Complete)
Launch Date: 10 March 2023
Launch Site: Florida
Payload: 40 OneWeb Satellites
Launch Vehicle: Falcon 9 (Space X)
Space Vehicles:#s 543-582

Launch #18 (Complete)
Launch Date: 26 March 2023
Launch Site: Satish Dhawan Space Ctr
Payload: 36 OneWeb Satellites
Launch Vehicle: Polar Sat (New Space India)
Space Vehicles:#s 583-618

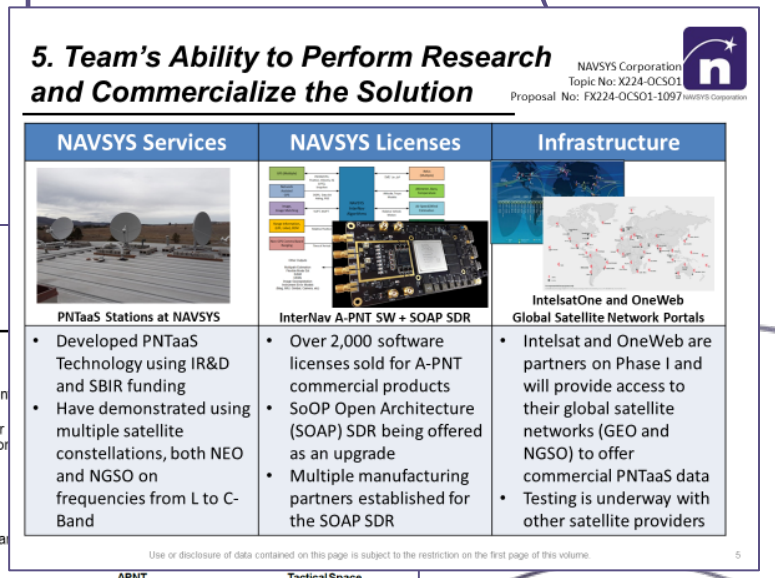


Launch #19 (Scheduled)
Launch Date: 10 May 2023
Launch Site: Vandenberg CA
Payload: 30 OneWeb Satellites
Launch Vehicle: Falcon 9 (Space X)
Space Vehicles:#s 619-648

Alt-PNT Commercial Viability

OneWeb Technologies / NAVSYS Partnering effort extends **beyond Defense** to the **Commercial market**.

- Extensive, worldwide OneWeb ground infrastructure provides global opportunity for PNTaaS signal correlation and cloud update.
- Constellation polar orbit provides dense, persistent far north (and far south) coverage.
- OneWeb business model encompasses both B2Gand B2B.
- Existing commercial contracts and interest:
  - **Long-haul logistics and warehousing**
  - **Commercial maritime**
  - **Energy development (at-sea and ashore)**
  - **Utilities**
  - **Law enforcement**



5. Team's Ability to Perform Research and Commercialize the Solution

NAVSYS Corporation
Topic No: X224-OCSO1
Proposal No: FX224-OCSO1-1097

NAVSYS Services	NAVSYS Licenses	Infrastructure
PNTaaS Stations at NAVSYS	InterNav A-PNT SW + SOAP SDR	IntelsatOne and OneWeb Global Satellite Network Portals
• Developed PNTaaS Technology using IR&D and SBIR funding • Have demonstrated using multiple satellite constellations, both NEO and NGSO on frequencies from L to C-Band	• Over 2,000 software licenses sold for A-PNT commercial products • SoOP Open Architecture (SOAP) SDR being offered as an upgrade • Multiple manufacturing partners established for the SOAP SDR	• Intelsat and OneWeb are partners on Phase I and will provide access to their global satellite networks (GEO and NGSO) to offer commercial PNTaaS data • Testing is underway with other satellite providers

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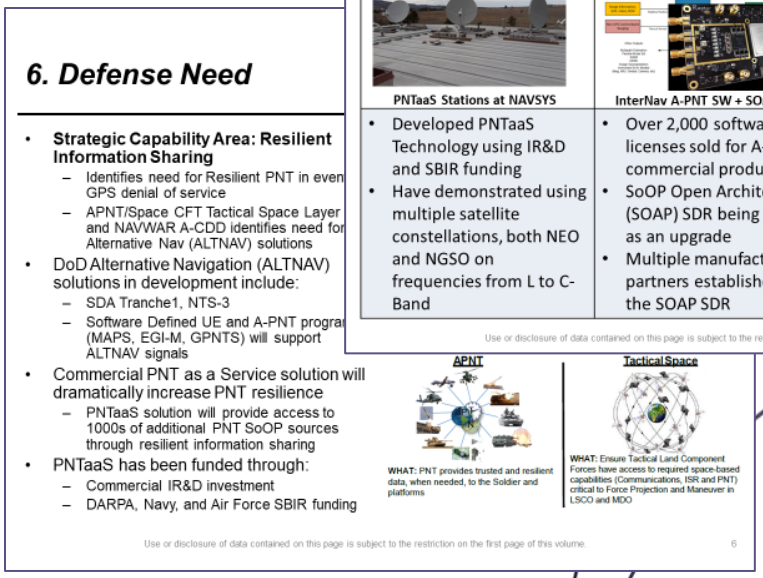

6. Defense Need

- **Strategic Capability Area: Resilient Information Sharing**
  - Identifies need for Resilient PNT in even GPS denial of service
  - APNT/Space CFT Tactical Space Layer and NAVWAR A-CDD identifies need for Alternative Nav (ALTNAV) solutions
- DoD Alternative Navigation (ALTNAV) solutions in development include:
  - SDA Tranche1, NTS-3
  - Software Defined UE and A-PNT progra (MAPS, EGI-M, GPNTS) will support ALTNAV signals
- Commercial PNT as a Service solution will dramatically increase PNT resilience
  - PNTaaS solution will provide access to 1000s of additional PNT SoOP sources through resilient information sharing
- PNTaaS has been funded through:
  - Commercial IR&D investment
  - DARPA, Navy, and Air Force SBIR funding

APNT

WHAT: PNT provides trusted and resilient data, when needed, to the Soldier and platforms

Tactical Space

WHAT: Ensure Tactical Land Component Forces have access to required space-based capabilities (Communications, ISR and PNT) critical to Force Projection and Maneuver in LSCO and MDO

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Conclusions

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- PNTaaS provides precision PNT in the absence of GPS leveraging existing SATCOM as SoOP
- PNTaaS accuracies approach GPS (~ 5 m RMS) with sufficient signals and geometry
- SATCOM frequencies (3-30 GHz) provide resilience in presence of interference
- PNTaaS Reference integration with Master clocks at USNO and NIST will tie PNTaaS master time to GPS
- Proposing to government sponsors a pilot program to allow performance evaluation of PNTaaS including Monitor station installations with multiple commercial SATCOM providers leveraging PNTaaS open architecture services

Reference

- A. Brown, D. Nguyen, J. Redd, T. Silva, S. Huerta, A. Linan, J. Passehl, “PNT as a Service (PNTaaS): Providing a Resilient Back-up to GPS by Leveraging Broadband Satellite Constellations and Ground Infrastructure,” IEEE/ION PLANS 2023, Monterrey, CA, April 27, 2023.