PNT as a Service (PNTaaS) Leveraging Commercial SATCOM

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GPS Risk Levels

	GPS Available		GPS Unavailable Local/Regional			GPS Unavailable Global	
Threat Conditions Solutions	1. Permissive	2. Challenged	3. Short Local GPS Outage	4. Long Local GPS Outage	5. Long Regional GPS Outage	6. Long Global GPS Outage	7. Day Without Space
Mil GPS	MGUE	MGUE					
Antenna	Interference Protection	Interference Protection					
Inertial/Clock			A-PNT	PNTaaS SDR updates bound inertial/clock error growth	PNTaaS SDR updates bound inertial/clock error growth		
Local PNTaaS Terminal				PNTaaS SDR updates bound inertial/clock error growth	PNTaaS SDR updates bound inertial/clock error growth		
PNTaaS Network						Global PNTaaS with COMSATCOM	Global PNTaaS with COMSATCOM

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

*A-PNT: Assured Positioning Navigation and Timing

PNT as a Service (PNTaaS)

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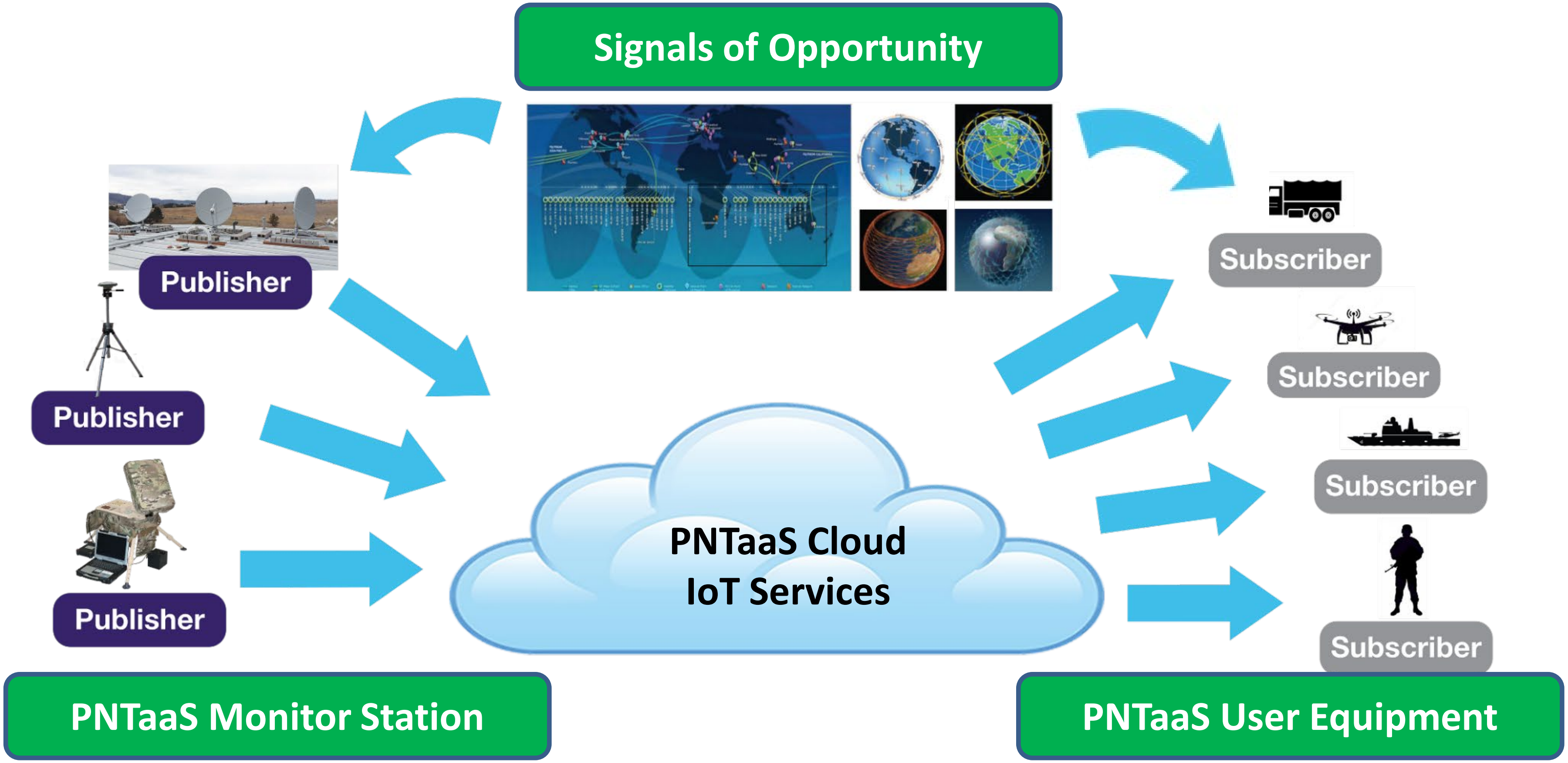

GNSS versus SATCOM Operation

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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

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

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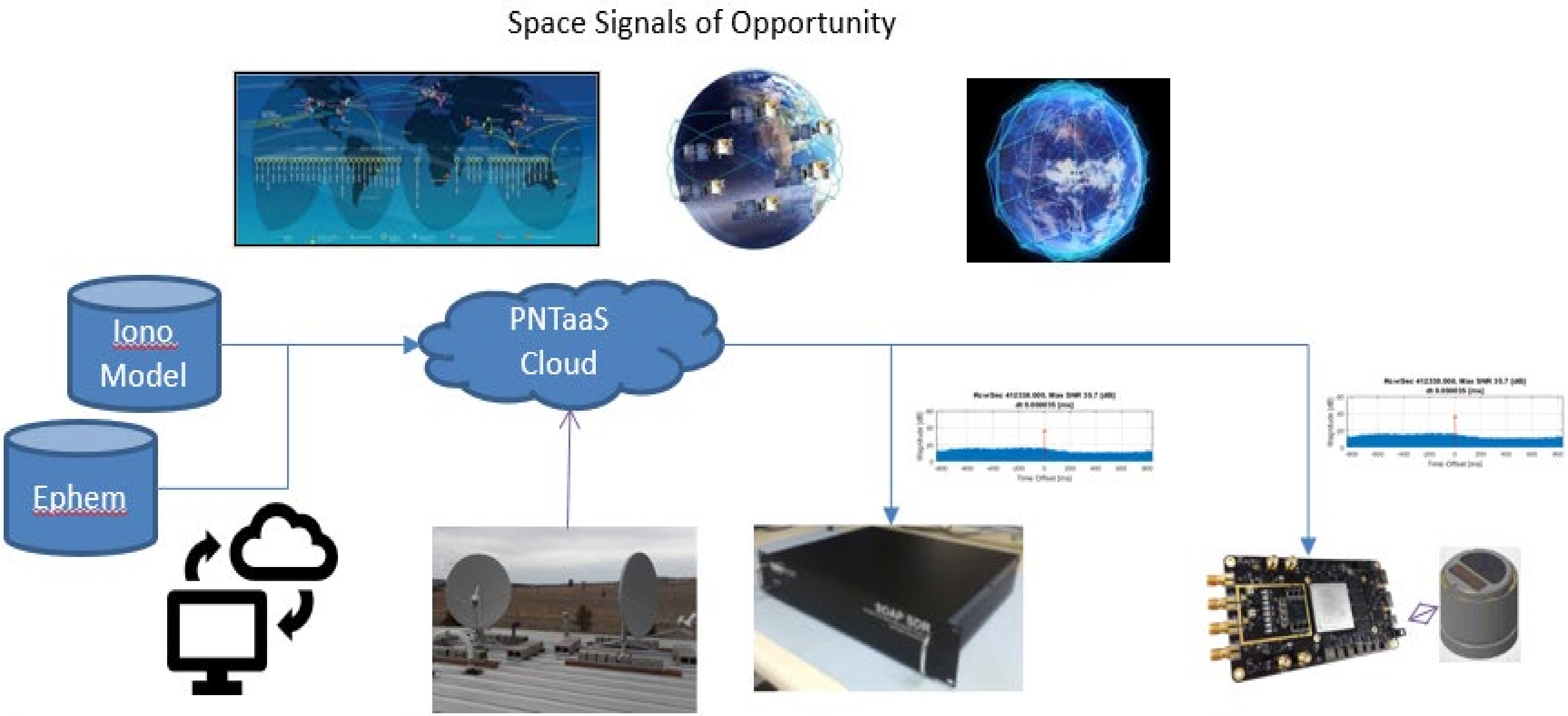
Band	Freq	SoOP	Orbit
L	1 – 2 GHz	GNSS, Iridium Inmarsat	MEO GEO
S	2 – 4 GHz	GlobalStar TDRS COSMIC-2	MEO GEO LEO
C	4 – 8 GHz	Xona Intelsat, Telesat, SES, etc.	LEO GEO
X	8 – 12 GHz	WGS, Skynet	GEO
Ku	10.7–12.7 GHz 12 – 18 GHz	OneWeb, SpaceX DBS, Viasat	LEO GEO
Ka	17.8-18.6 GHz	Telesat, Kuiper, O3B ViaSat,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

Existing SATCOM systems have many more frequency allocations than GNSS

PNTaaS CONOPS

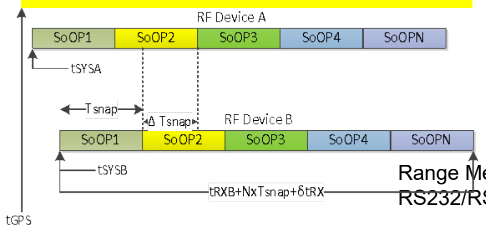


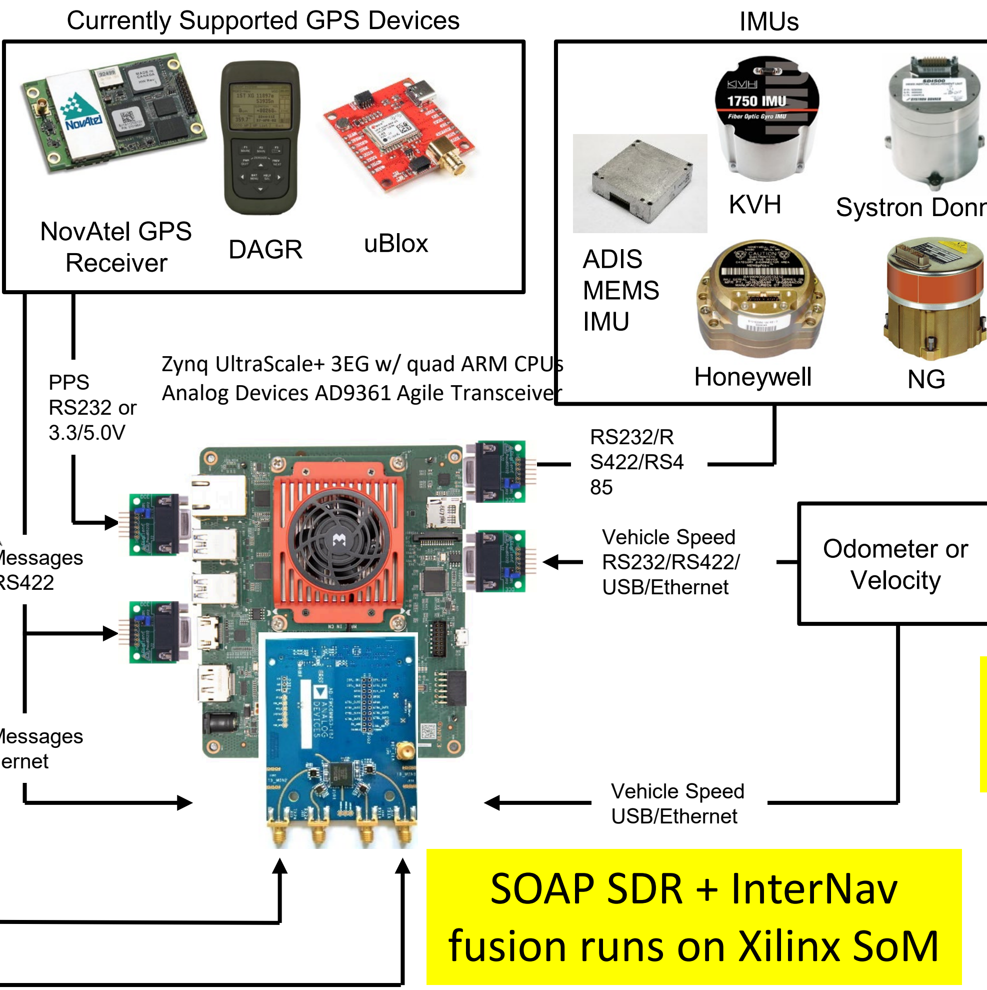
1. PNTaaS Server builds list of available SoOP and publishes SoOP Location data
2. Monitor Station observes SATCOM SoOP with high gain antenna and publishes SoOP Snapshot
3. PNTaaS Reference SDR receive PNTaaS SoOP and publishes TOA relative to Master Clock
4. Remote PNTaaS SDR sets local SoOP Sequence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

SoOP Open Architecture PNT (SOAP) SDR

Modular design supports multiple GPS receivers

Time synced fast sequencing supports 100s of SoOP

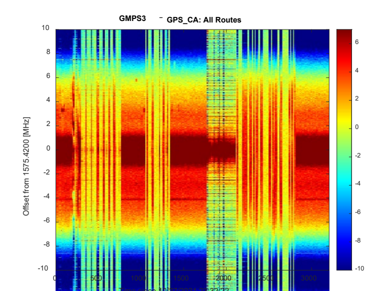




Drivers included for most COTS inertial units

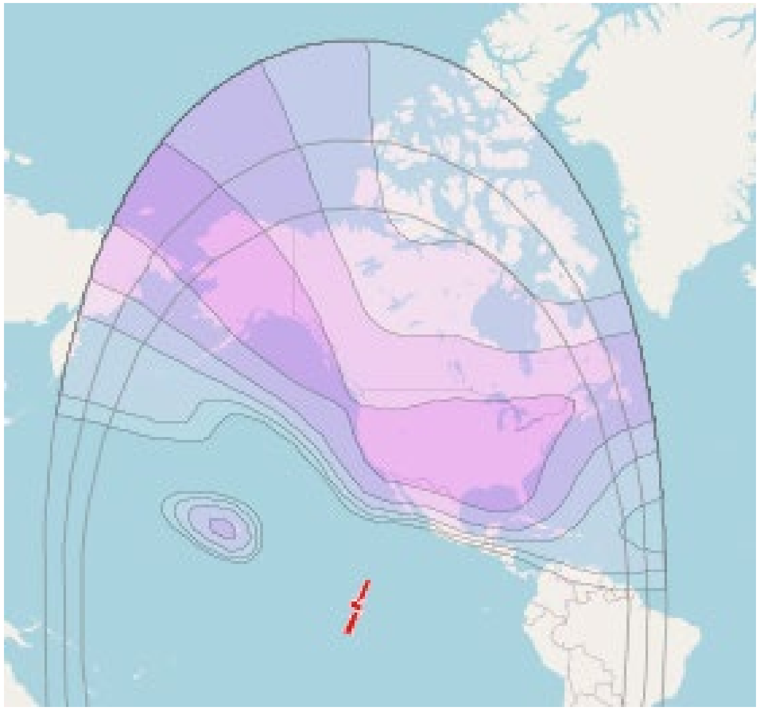
Precise time tags for external aiding sensors

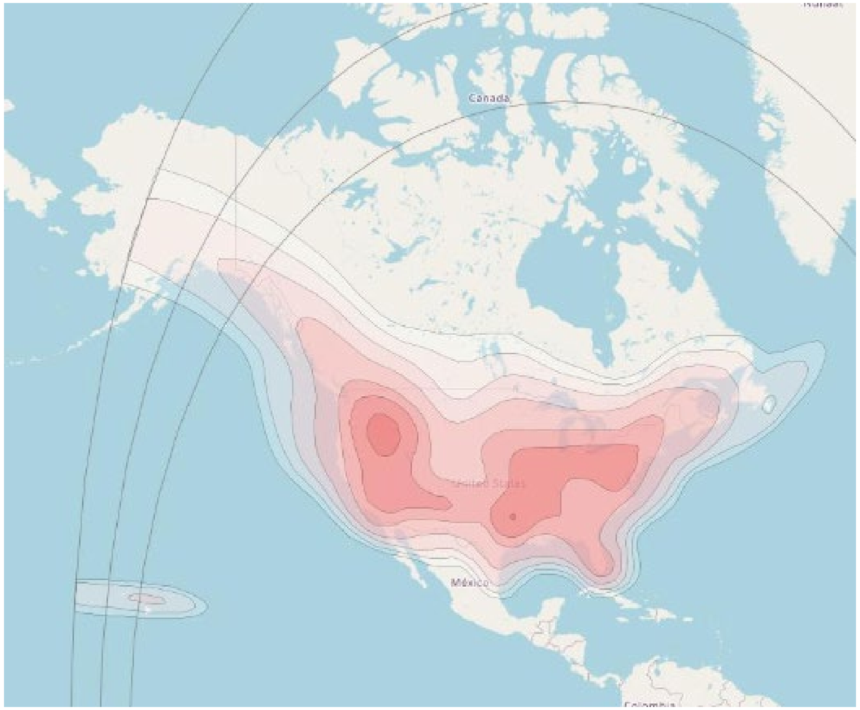
Real-Time FFT for RF SA and ML



SOAP SDR + InterNav fusion runs on Xilinx SoM

Example GEO SoOP Footprints

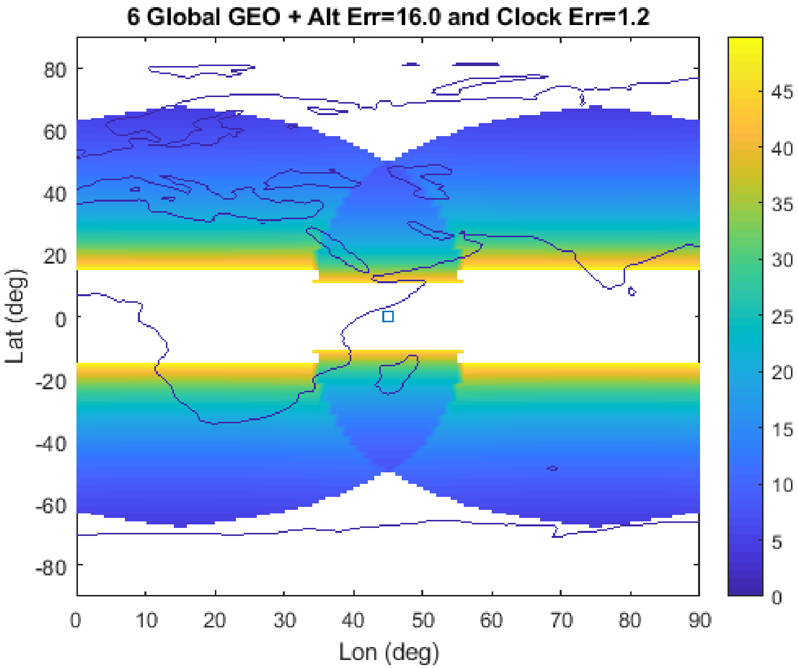


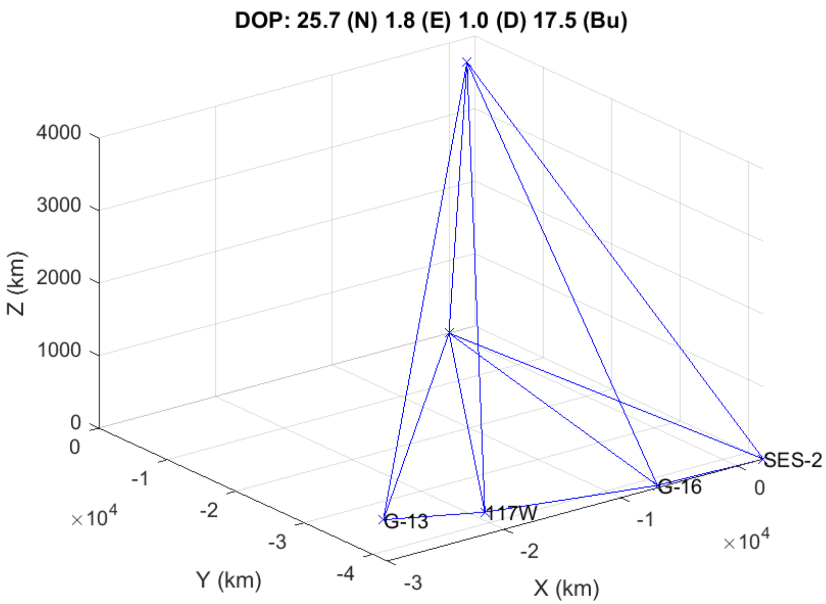


GALAXY-30 (C-Band)
~ 38 dB-Hz C/N0
(20 MHz BW)

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

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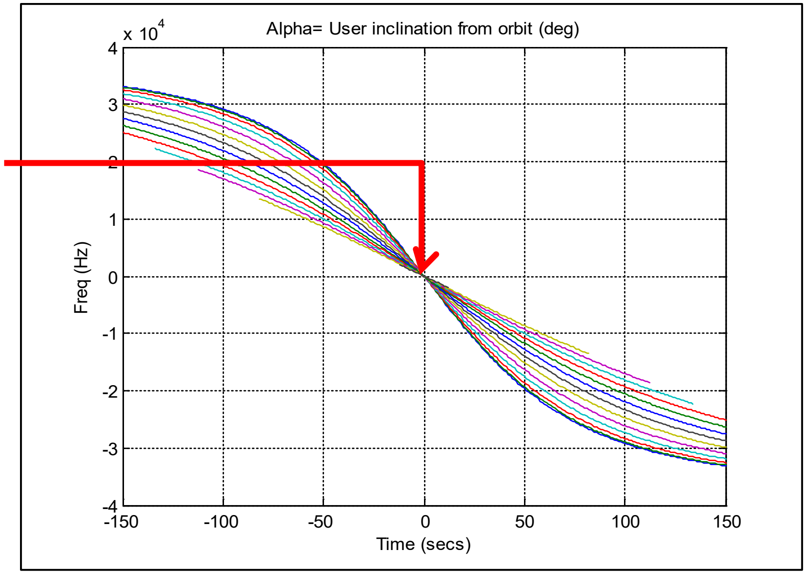
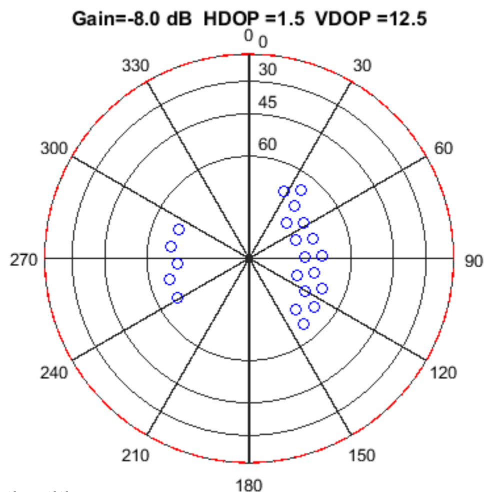
- Doppler tracking of LEO SV "transit" across the sky gives 2DOF
  - Time of closest point in transit (θ)
  - Doppler Rate of change at θ gives declination from orbit (α)
- User's inertial/clock solution needs 4D geometry to correct PNT offset
  - 2 SV transits (4DOF)
- Example of LEO "Transit" Geometry
  - 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

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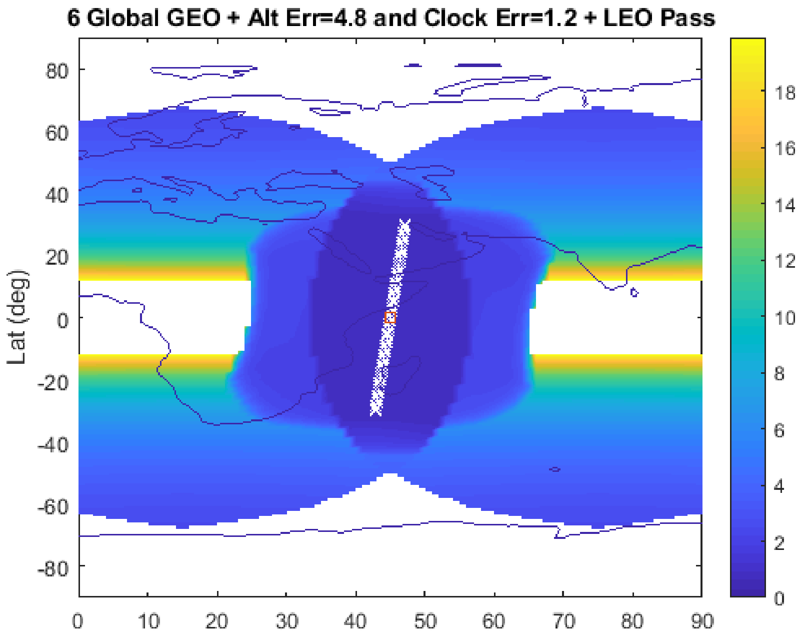
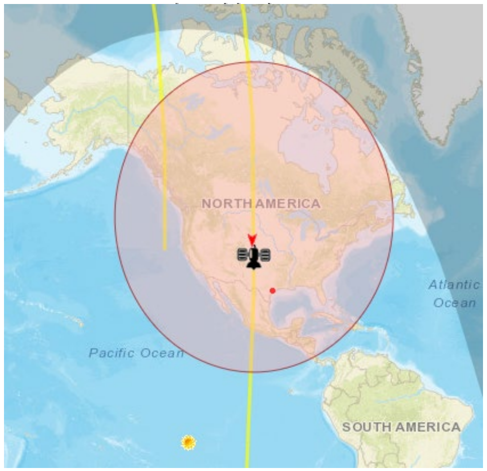
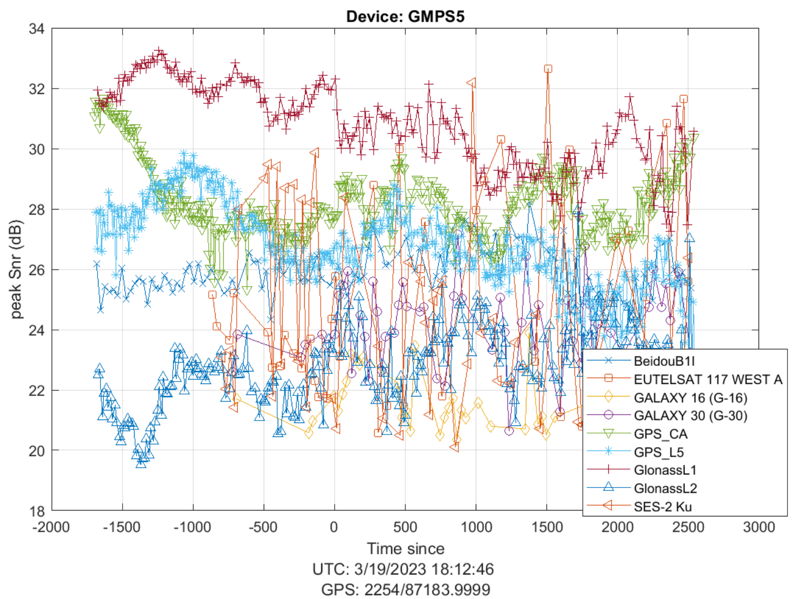
- GEO + occasional LEO pass “transit” will provide 4D geometry
- Benefits are global coverage and periodic clock calibration
- Doppler-only updates are sufficient when have an accurate SDR clock

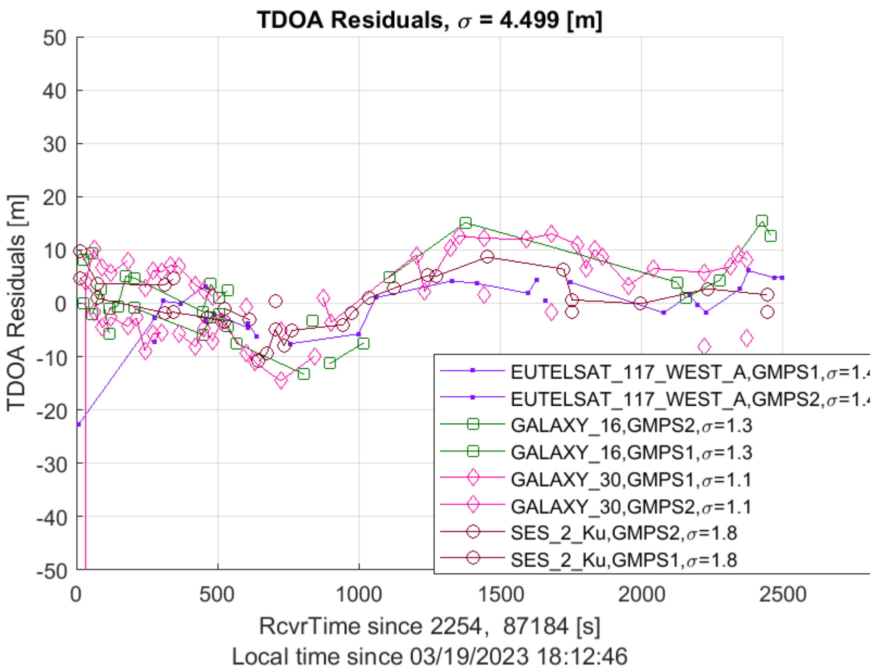


Example OneWeb Footprint (Ku-Band)



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

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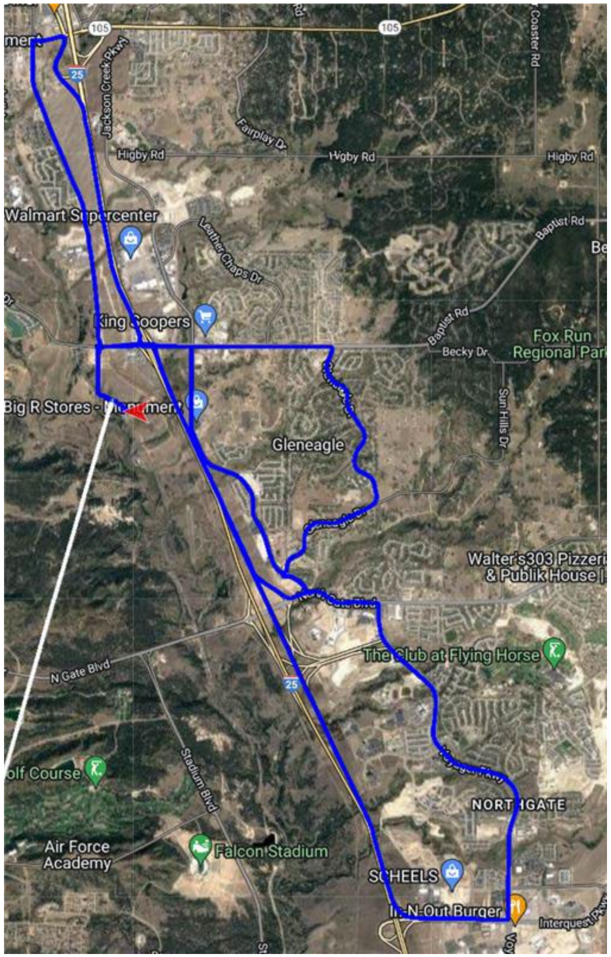
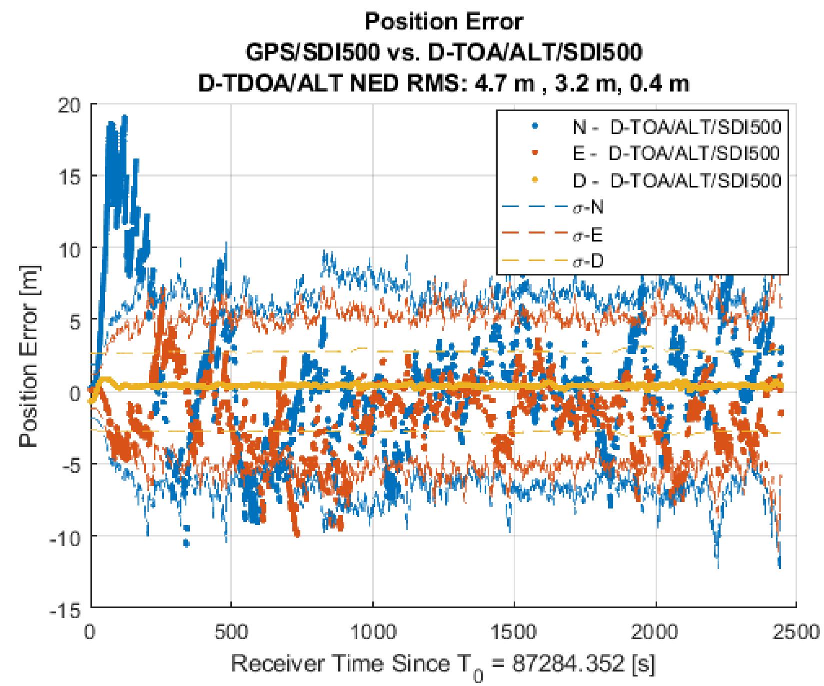
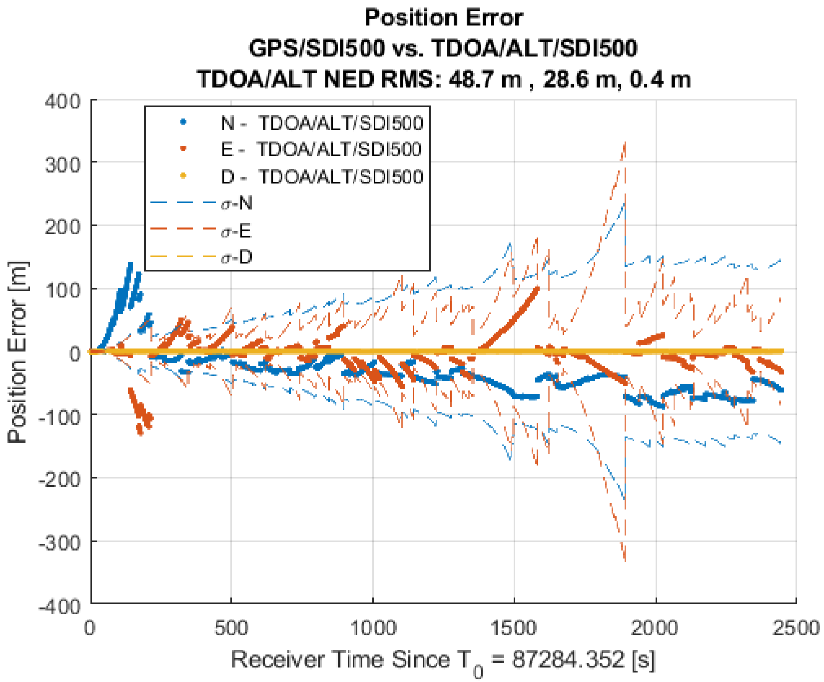




GEO + Alt only PNTaaS Results

- 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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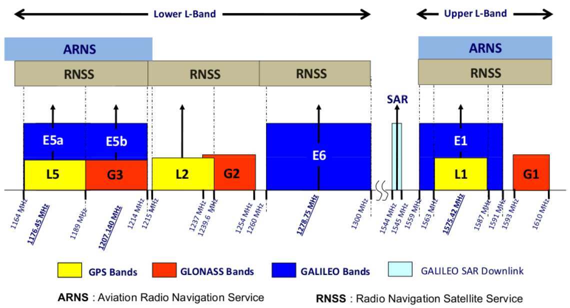

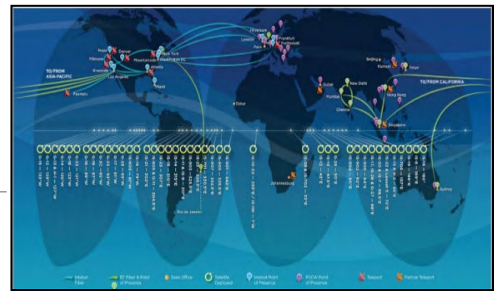

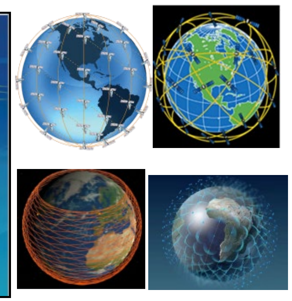

INTELSAT Viasat SES Government Solutions TELESAT OneWeb STARLINK

Problem/Opportunity

All GNSS signals are in L-band (1.1-1.6 GHz) and are vulnerabale 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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<table>
<tr><th>PNTaaS Monitor</th><th>SOAP SDR Licenses</th><th>Global Deployment</th></tr>
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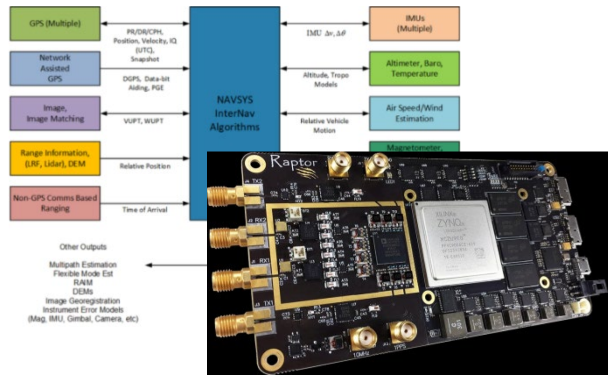
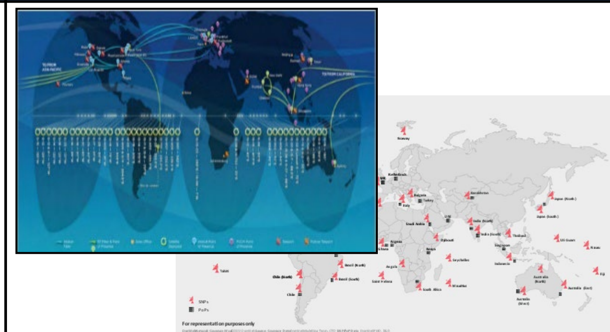
PNTaaS Monitor Stations</td>
<td>

InterNav A-PNT SW + SOAP SDR</td>
<td>
IntelsatOne , Viasat and OneWeb Global Satellite Network Portals</td>
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<tr>
<td>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</td>
<td>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</td>
<td>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</td>
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Ongoing PNTaaS Activities

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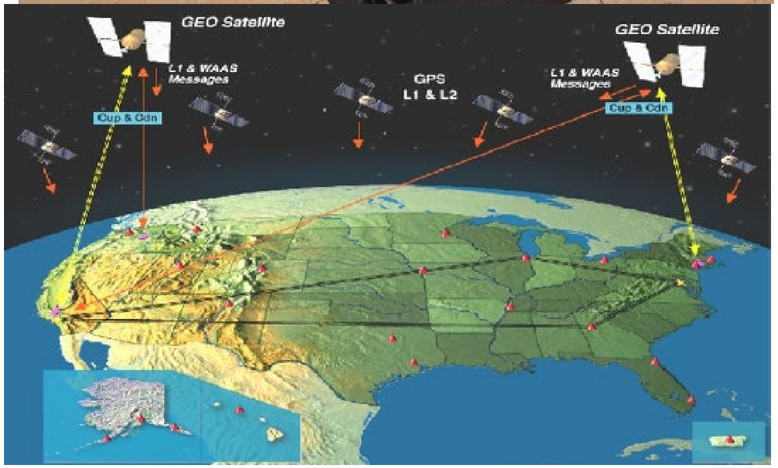

- Integration of PNTaaS SDR with OneWeb and Viasat SATCOM terminals
- Adding cooperative GEO ALTNAV signals to PNTaaS for “off-net” operation leveraging NAVSYS WAAS Ground Station technology
- Upgrading SOAP SDR signal processing for operation with new signals and additional observation types

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
- Open architecture allows distribution of multiple SoOP from different constellations and addition of different signal types for PNT
- SOAP SDR provides framework for integrating new signals and includes Machine Learning for SoOP dynamic selection
- Opportunities for partnering with NAVSYS for PNTaaS deployment and integration of new signal types