Department of Transportation
Office of the Assistant Secretary for Research and Technology (OST-R)

GPS/GNSS Interference Detection: Notification & Action Framework
Space-Based Positioning Navigation & Timing Advisory Board
November 16, 2022

DOT Embraces The PTA Principle

- **Protect:**
  - Ensure Performance Monitoring of Space-Based Civil PNT Services
  - Implement Interference Monitoring Capabilities to Identify, Locate, and Attribute PNT Service Interruptions and Threats = **IDM**
  - Prevention of Harmful Interference
  - Facilitate international coordination for development of monitoring standards

- **Toughen:**
  - Authenticate signals and harden user equipment (receiver/antenna/algorithms)

- **Augment / Adopt:**
  - Implement and utilize GPS augmentations and Complementary PNT services
  - Facilitate adoption of Complementary PNT into end-user applications

DOT SPD-7 High-Level PNT IDM Strategy

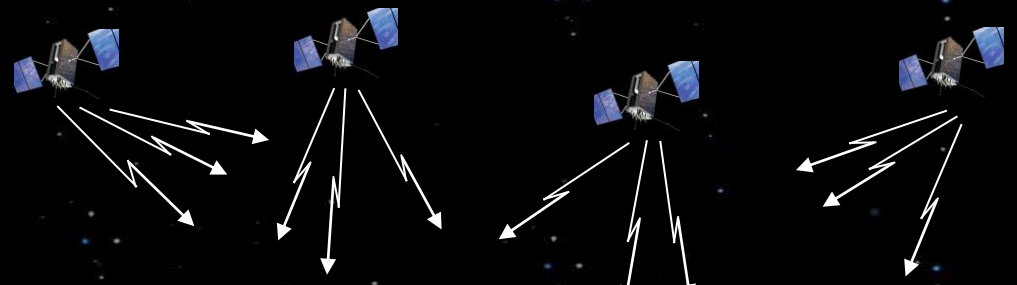
- **Actively Detect and identify L-Band Interference Emissions**
  - Focus on In-Band and Adjacent Band Interference
  - In partnership with other Federal Departments/Agencies

- **Leverage Space, Ground, Fixed, Transportable, and Mobile**
  - Sensor Equipment Already in Operation | System-of-Systems
  - Adapt/Enhance to Cover GNSS Interference

- **Joint Federal, State and Local – Civil, Military**
  - Establish Multi-Federal-State MOA & CONOPS

- **State and Local Law Enforcement Involvement**
  - Focused for Critical Ports and Infrastructure Protection

DOT IDM Joint Concept of Operations



Space-Aviation Segments Automated Reports of GNSS Anomalies = SV Observables, ADS-B, Datalink, Voice for light GA non-datalink capable

ADS-B

Datalink

Voice

SatCom

(CENTER) (TWR/TRACON)

Space-Airborne detection to notify space-aeronautical operators of potential jamming or spoofing including Space vehicle and aircraft report generation

Known event information is reported to transportation stakeholders after being 'operationalized' by DOT; assessment results in notifications of appropriate activities (e.g., Aviation, Maritime, Telecom, Finance, OGA)

OEMs and Suppliers

DOD | DHS | DOC | Other Government Agencies (OGA)

State Operators / Service Centers/ Internal Stakeholders

National International Stakeholder Communications

Action/advisories to Field Facilities

Data Sets collected from multiple vehicles.

Timely processing of automated data from transport vehicle, AIS, Fixed Sites and other sources by 3rd party provides for timely notification of event-effected area

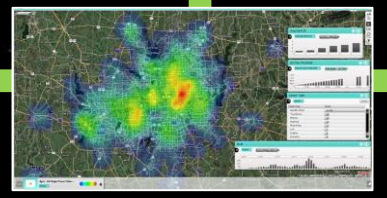
GNSS receivers report feeds from Vessels, Vehicles, Facilities Affected

GNSS receivers report feeds from Space Vehicles & Aircraft Affected

Interagency Processing Center COP Analysis, Cyber Assessments and Impact Notification

Other Inputs | Other Outputs

Affected Area Heat Map

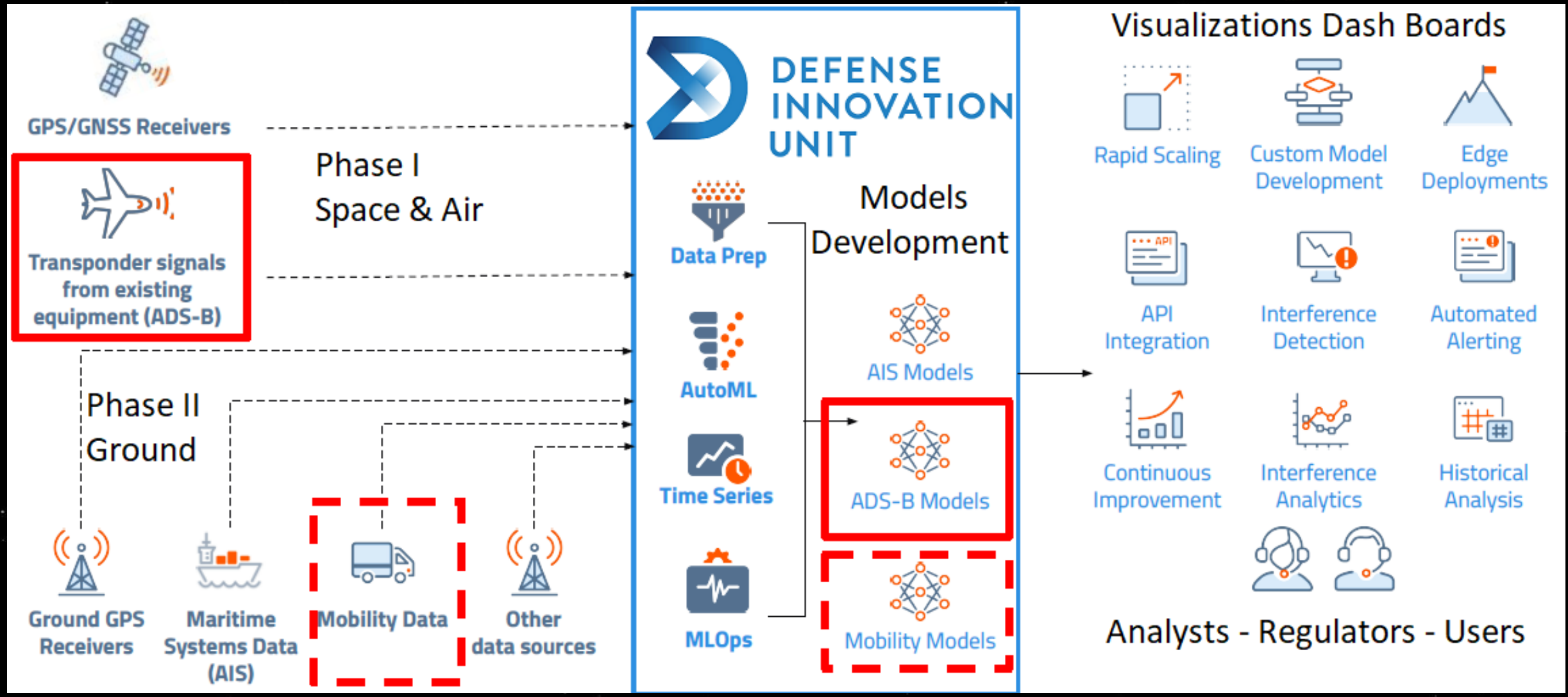


OPS COMMAND CENTERS

DOMESTIC EVENTS NETWORK (DEN) | JOINT AIR TRAFFIC OPERATIONS COMMAND (JATOC) | NOTICES TO AIR MISSION (NOTAMS)

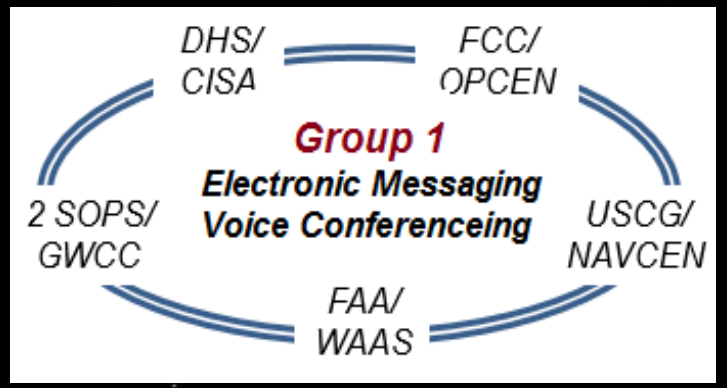
Vessel, Vehicle & Fixed Building detection (low-cost or installed electronics) to notify users of potential jamming or spoofing including auto-alert report generation

DOT-DoD Joint Harmonious Rook IDM Initiative



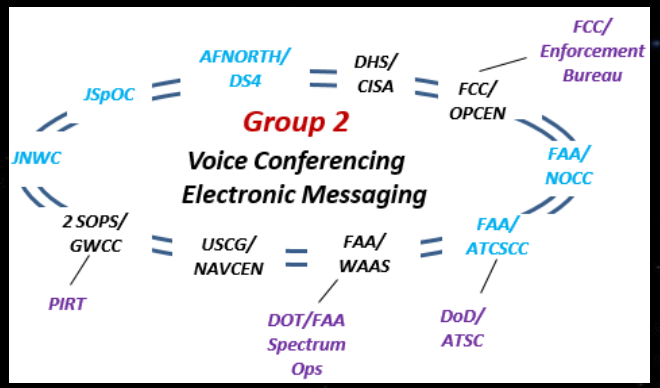
WHY DOT IDM = Denver, CO & Dallas, TX

- **Federal Government IDM Dependency** = Present IDM interagency posture reliant on User Identification, Detection and Reporting of GPS Interference, based on subjective user assessment of operational disruptions or impacts.



INITIAL - TRIGGERS START OF THE CRUCIBLE **GROUP 1** CONFERENCING AND INFORMATION SHARING BETWEEN THE FIVE (P5) 24/7/365 OPERATIONS CENTERS

PERSISTENT - ELEVATES TO CRUCIBLE **GROUP 2** CONFERENCING AND INFORMATION SHARING BETWEEN ADDITIONAL OPERATIONS CENTERS AND SUBJECT EXPERTS



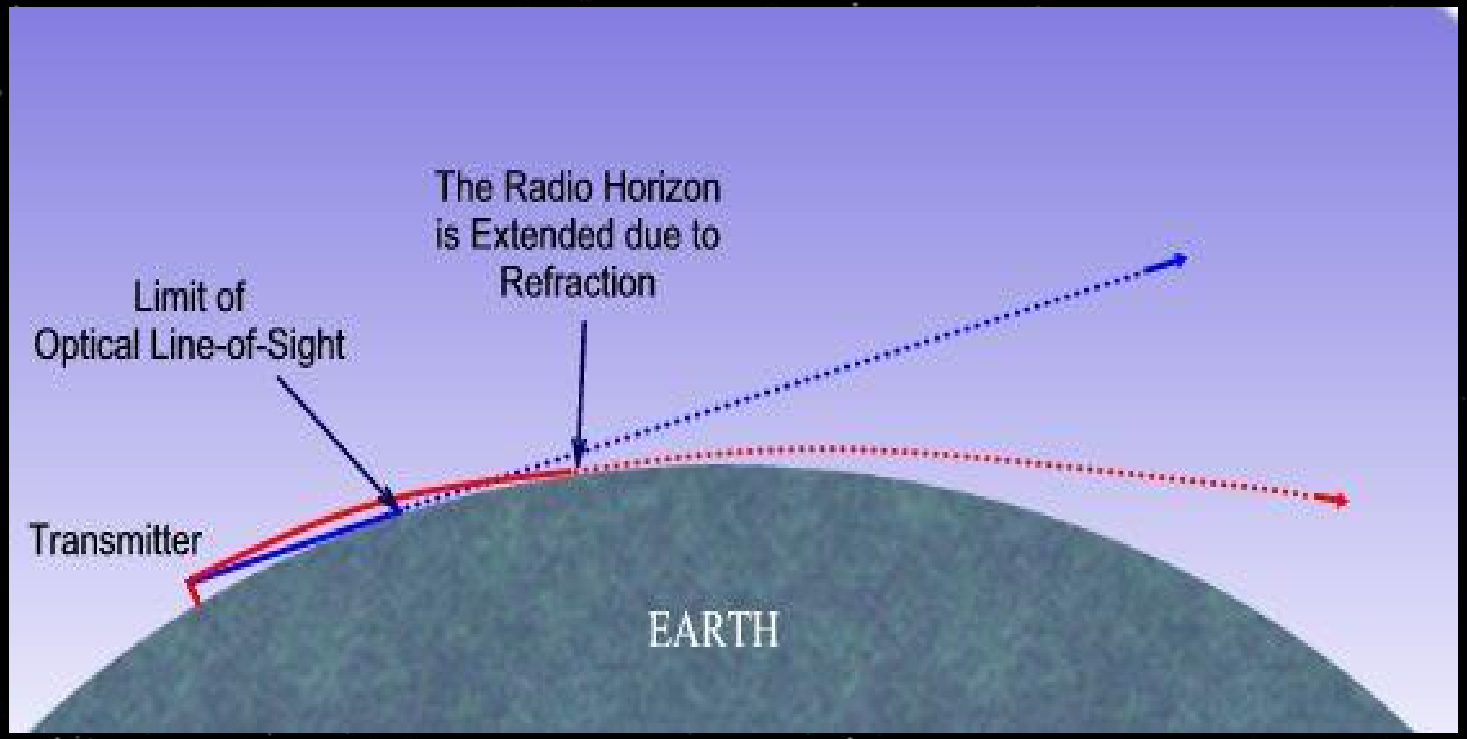
- **Technology Implementation Is Needed** = Independent dedicated technology for Automated Monitoring of GPS Interference Signals by chartered Federal interagency partners is required to improve faster resolution posture.

The Physics of Radio Propagation Line Of Sight

- **Denver Event** ~ 33.5 hours from 1/21/2022 to 1/23/2022 = RLOS 2 mi - Located
- **Dallas Event** ~ 46.4 hours from 10/16/2022 to 10/18/2022 = RLOS 126 mi - Not Located

Optical Line of Sight ends approximately where the straight line from the transmitter becomes tangent to the Earth's surface.

The decrease in the index of refraction with altitude causes radio wave to bend downward. Hence the ***Radio Line of Sight*** is longer than Optical LOS.



$$RLOS\ (nmi) = 1.23 \cdot \sqrt{h}$$

(h = height in feet, AMSL)

Why The Difference in IDM Performance

- **Denver Event:**
  - With Ground Fixed Sites Reports in The Aurora, CO Area
  - With Telecommunications Sites Reports with GPS Time Synchronization Issues in Aurora, CO Area
  - With Aircraft GPS Signal Reception Interruptions in Denver Terminal and Enroute Airspace

  Area of Interest (**AOI**) Resulted in a 2 Square Mile Ground Search = **We Won**

- **Dallas Event:**
  - With Aircraft GPS Signal Reception Interruptions in Dallas Terminal Airspace and Fort Worth Center Enroute Airspace **ONLY**. No other Ground Infrastructure Reports

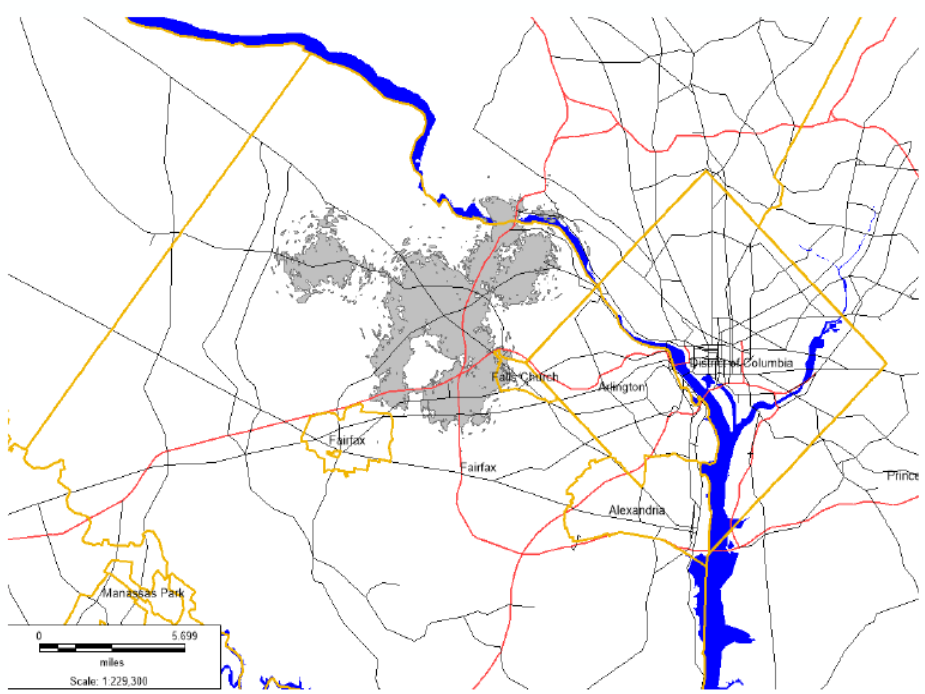
  Area of Interest (AOI) Resulted in a 126 Square Miles Ground Search = **No Win**

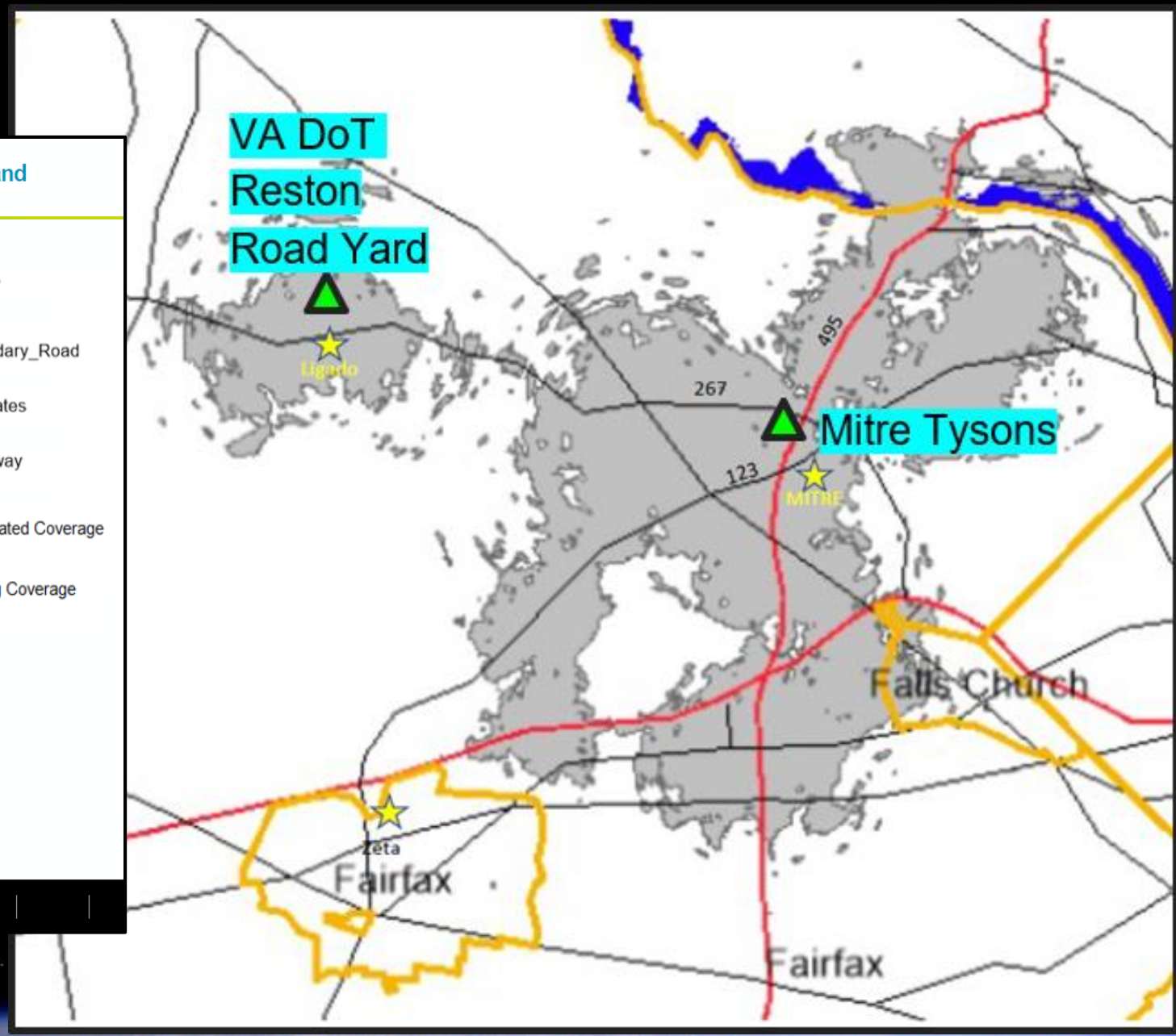
DOT Strategic Spectrum Monitoring Capability for Ligado

- Important to have a “before” and “after” characterization of the spectrum – goal is to deploy monitoring at least 30 days in advance
- Based on current DOT/OST-R effort, working towards the earliest Ligado deployment (On or After September 30, 2022) which has since passed
- Two major components:
  - Develop interference metrics that correlate harmful impact to GPS receivers
  - Develop mobile monitoring system for pre- and post-deployment RF surveys on-location and attribution of potential harmful interference
- Significant stakeholder engagement, feedback, and support of proposed harmful interference metrics and monitoring capability

Ligado Initial Proposed Deployment

Anticipated Coverage by County of Ligado's and its Customers' Terrestrial Network and Services





ligado NETWORKS

Monitoring System Development

- Spectrum monitoring system
  - Mobile system to support primarily static scenarios
  - Mobile system can respond to selected Ligado-related user filed complaints
  - Signal record/playback function
  - Suite of representative GPS receivers

- Establish a spectrum baseline prior to Ligado operation
  - Radiofrequency (RF) environment survey, test protocol
  - Characterize other RF sources of error/noise (e.g. non-Ligado RF operations, multipath)
  - Characterize representative GPS receiver operations
- During Ligado operations, conduct live sky recording and assess and correlate potential GPS receiver(s) impact
  - Ability to playback in the lab if/when other GPS receivers are identified by users

Harmful Interference Metric(s)

- Interference can cause signal degradation leading to an increase of ranging and position error
- Therefore, the initial DOT approach aimed at protecting user-impacting function upstream by insuring the upstream signal quality degradation quantified as a CNR degradation of no more than 1 dB
- Previous work also considered harmful impact by assessing the impact on acquisition time as well as loss of code and carrier tracking due to interference
- In this current approach, and given FCC's feedback on harmful interference, the interference measurements will characterize interference impact using a larger set of metrics

CNR Degradation	[dB]
Loss of Lock	[unitless]
Acquisition Time Increase	[%]
Ranging Error: $\sigma_R(Interf_{on})$	[m]
Ranging Error Degradation: $\frac{\sigma_R(Interf_{on})}{\sigma_R(Interf_{off})}$	[%]
Position Error : $\sigma_p(Interf_{on})$	[m]
Position Error Degradation: $\frac{\sigma_p(Interf_{on})}{\sigma_p(Interf_{off})}$	[%]

Isolating Ligado Transmission Impact on Ranging Error

- Ranging error is calculated using two approaches
  - Pseudorange (PR) double differencing (DD) relative to a protected reference receiver
  - Detrended code-minus-carrier (CMC) and DD carrier phase when carrier phase measurements are also reported
- These techniques remove the ionospheric and tropospheric errors, receiver bias, and satellite ephemeris errors from PR measurements, leaving the baseline receiver noise, multipath, and interference induced errors
- In the absence of multipath, DD and CMC will isolate the interference induced ranging error degradation
- Accounting for multipath
  - Measurement location will be chosen to minimize change in the multipath environment throughout the measurement campaign
  - For antennas that allow the separation of active subassembly from the passive element a protected path is used as a reference to allow in-situ isolation of multipath impact
- Baseline measurements prior, a directional antenna and spectrum analyzer system will be used to ensure that all terrestrial emissions in the ~1526-1536 MHz frequency range are emanating from the Ligado transmissions

Summary

- PNT resiliency requires the need to detect, locate, and remove sources of interference as quickly as possible
- Relying on user reports for GPS/GNSS interference detection is extremely subjective and woefully inadequate
- Need to have a real-time Common Operating Picture of GPS/GNSS interference based on an automated detection capability
  - Provide notifications and allow shared situational awareness
  - Utilize user reports of interference to corroborate automated detections
- Direct attribution of the source of interference is critical to rapid mitigation

Acknowledgements

DOT/FAA: James Aviles, Ken Alexander, Sean Memmen

OST-R/Volpe: Stephen Mackey, Dr. Hadi Wassaf, Dr. Andrew Hansen, Chris Scarpone

MITRE: Dr. Chris Hegarty, Dr. Brady O'Hanlon, Watinur Rahman

Zeta: John Flake, Paul Traunero, Roger Ishimoto, Swen Ericson