



Doppler Positioning with LEO Satellites and Combination with NavIC

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- Overview of LEO constellations
- Doppler-based positioning and simulation
- DOP Analysis
- Types of positioning
 - NavIC only code-based positioning
 - LEO Doppler-based positioning
 - NavIC code + LEO Doppler-based positioning
 - NavIC + LEO code-based positioning
- Summary

Overview of LEO constellations

- Large four LEO constellations

Details*	Iridium NEXT**	OneWeb**	Starlink**	Kupier**
No. of Satellites	75	720	~3900 (April 2023)	3,236
Services	Resilient Timing (STL) by Satelles	Broadband	Broadband	Broadband

- Commercial PNT:
 - Xona Space Systems**
 - Low Earth Orbit Navigation System (LEONS) **

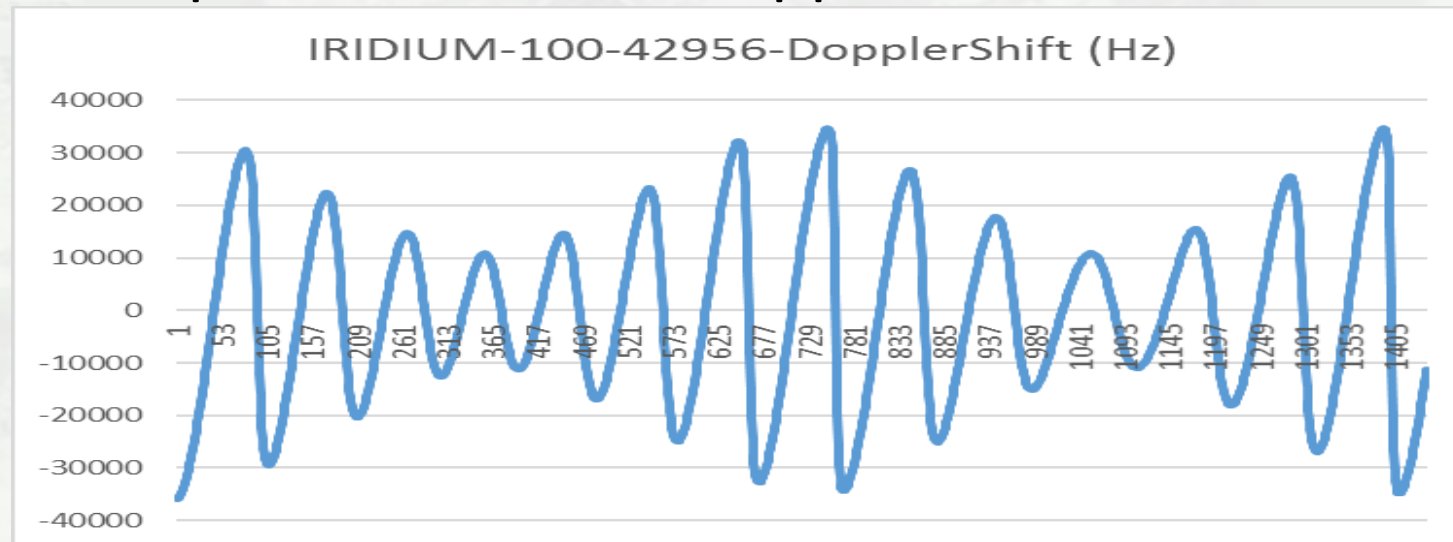
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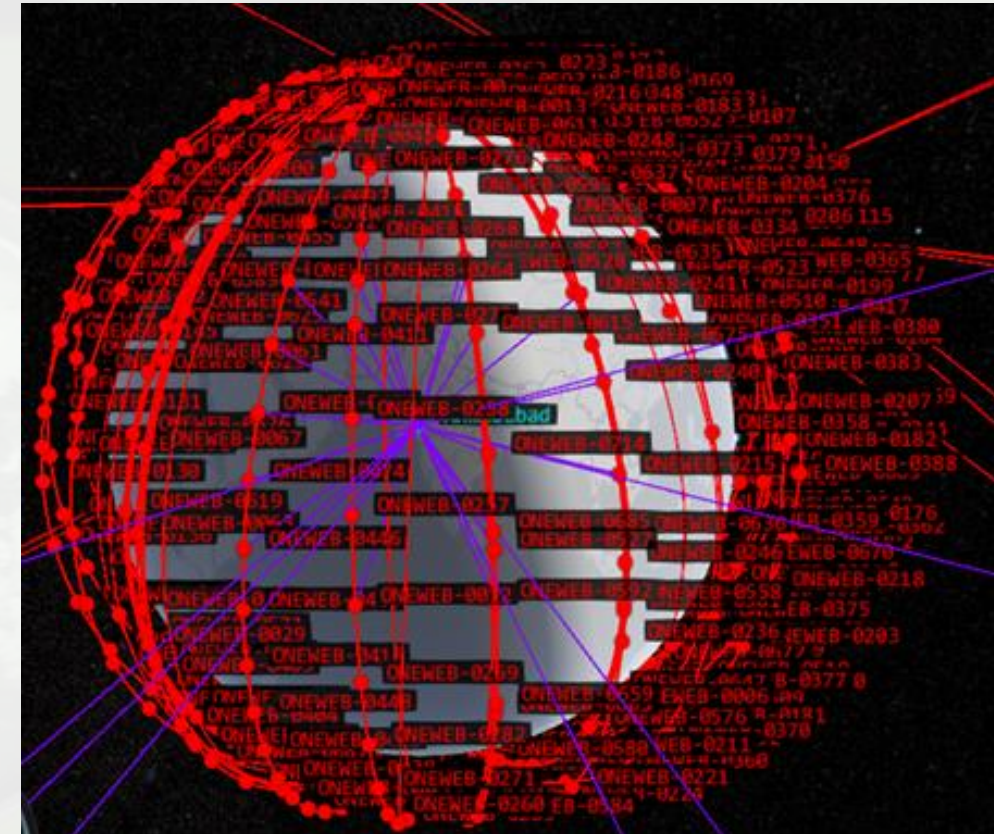
- Low Earth Orbit (LEO) satellites
 - High transmission power for broadband use
 - Low altitude and latency
 - Reduced launch cost
 - Use of COTS components
 - Atomic clock is not a must
 - Higher observability & redundancy in number of satellites
 - Indoor penetration
- LEO constellations – Signals of Opportunity
- Although signal structure is unavailable in public domain, Doppler observations can be obtained
- In GNSS-denied environment, positioning can be done, albeit, with lesser accuracy

Doppler-based Positioning

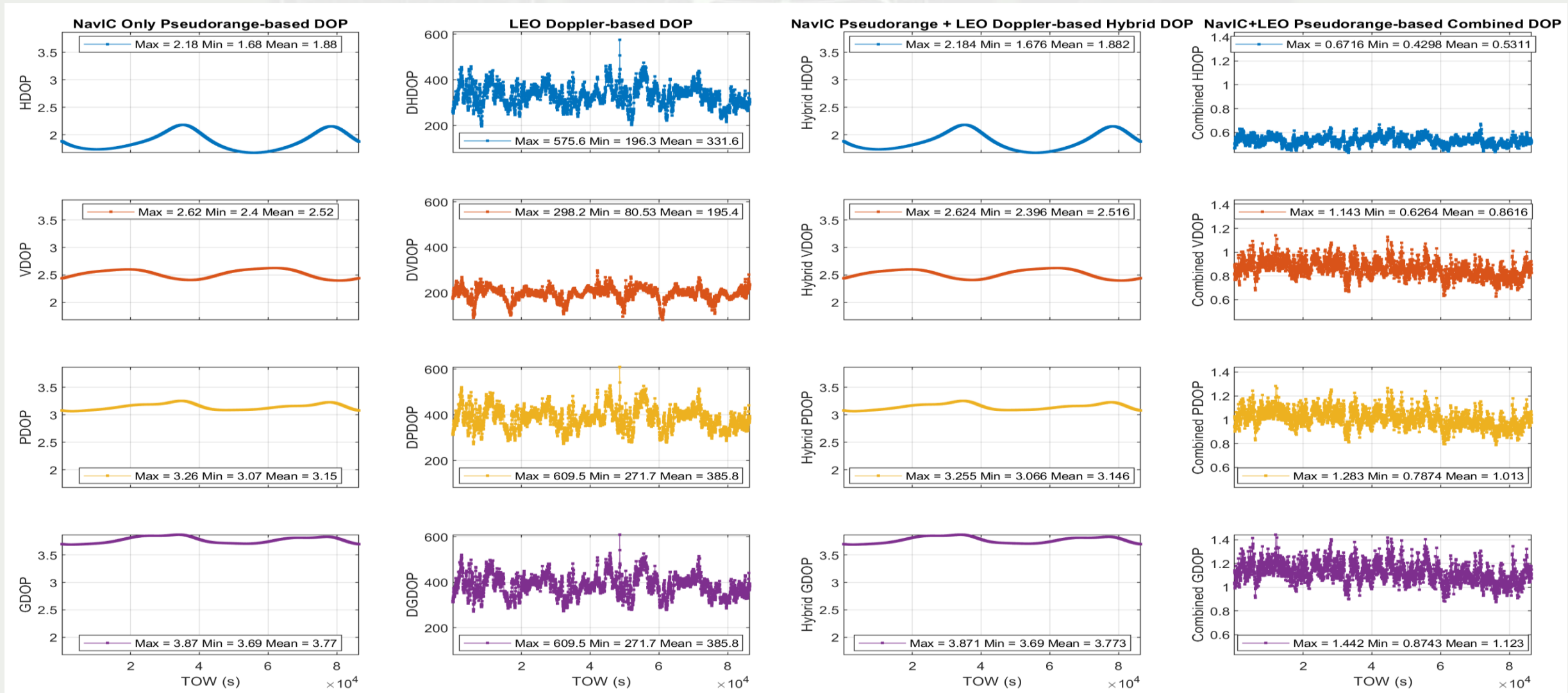
- Uses only Doppler observations from LEO satellites
- Initial coarse position and timing is required
- Satellite position error has no big impact
- Navigation solution is very sensitive to user clock drift, satellite velocity errors
- Example shows rapid variations in Doppler of an Iridium NEXT LEO satellite



- Simulation software developed to accept ephemeris information of **OneWeb** (LEO under consideration) and **NavIC**
- Software helps generate
 - Doppler observations with **random noise & no biases**
 - Satellite position & velocity
- Analysis is carried out using four types are combinations:
 1. NavIC only code-based positioning
 2. OneWeb Doppler-based positioning
 3. Hybrid of NavIC code + OneWeb Doppler-based positioning
 4. Combination of NavIC + OneWeb code-based positioning

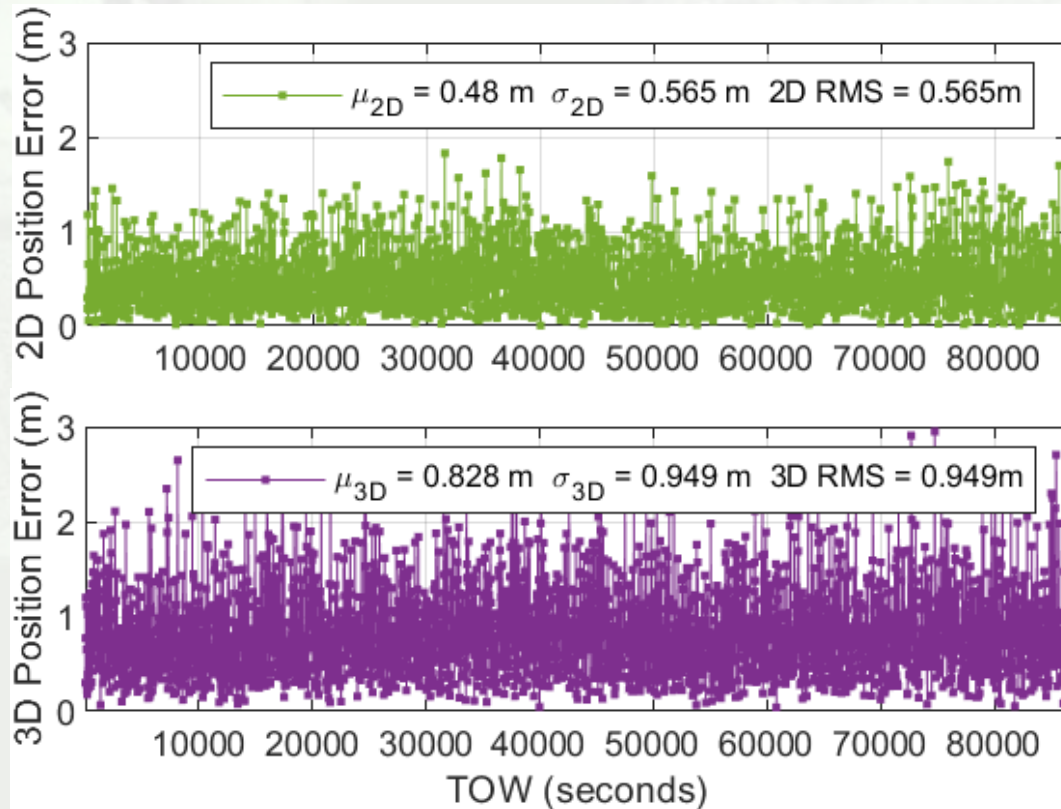


Dilution of Precision (DOP) analysis

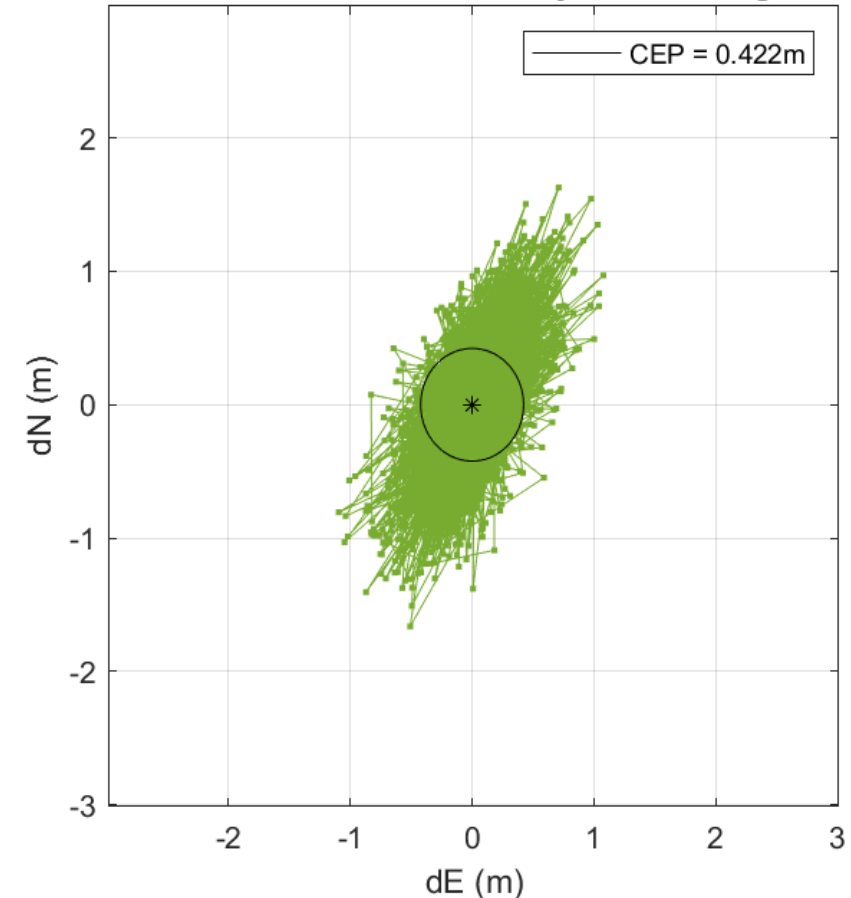


#1 Simulation - NavIC only Code-based solution

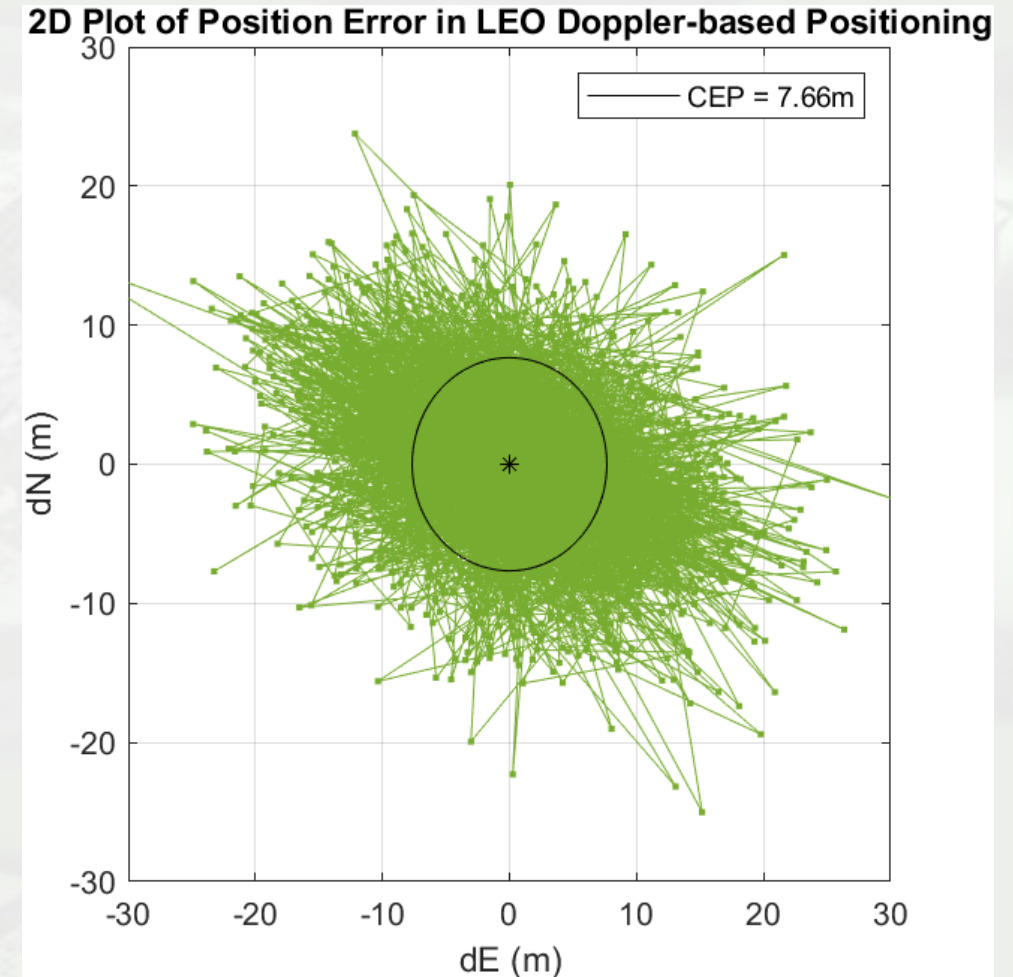
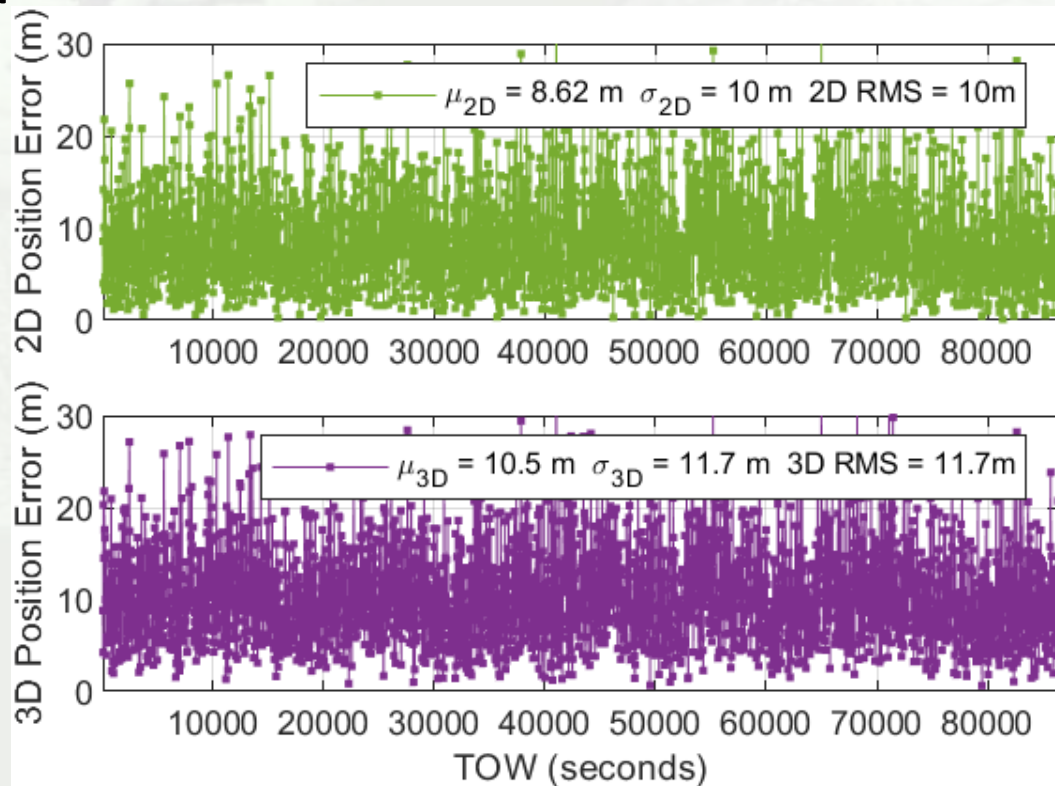
- Code-based solution with only 7 NavIC satellites
- No biases in observations



2D Plot of Position Error in NavIC Only Pseudorange Positioning

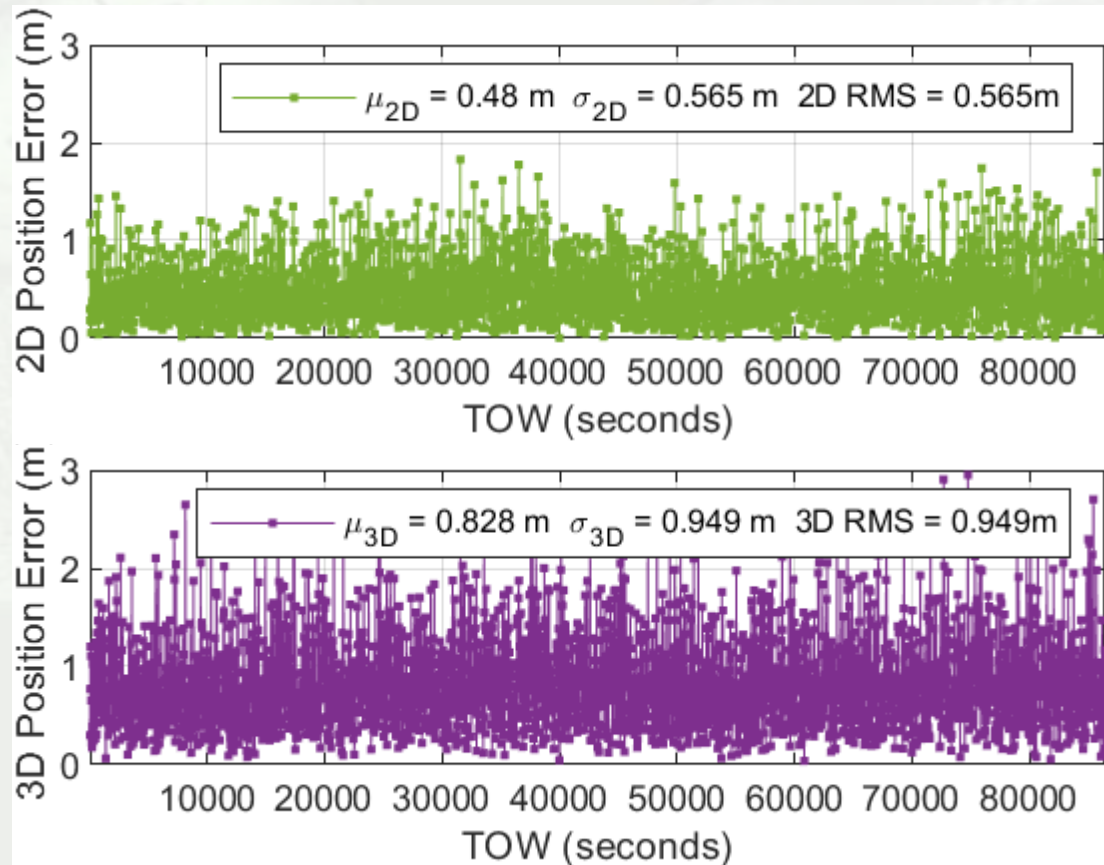


- Doppler-based solution using OneWeb satellites
- Large Doppler-DOP leads to increase in position error

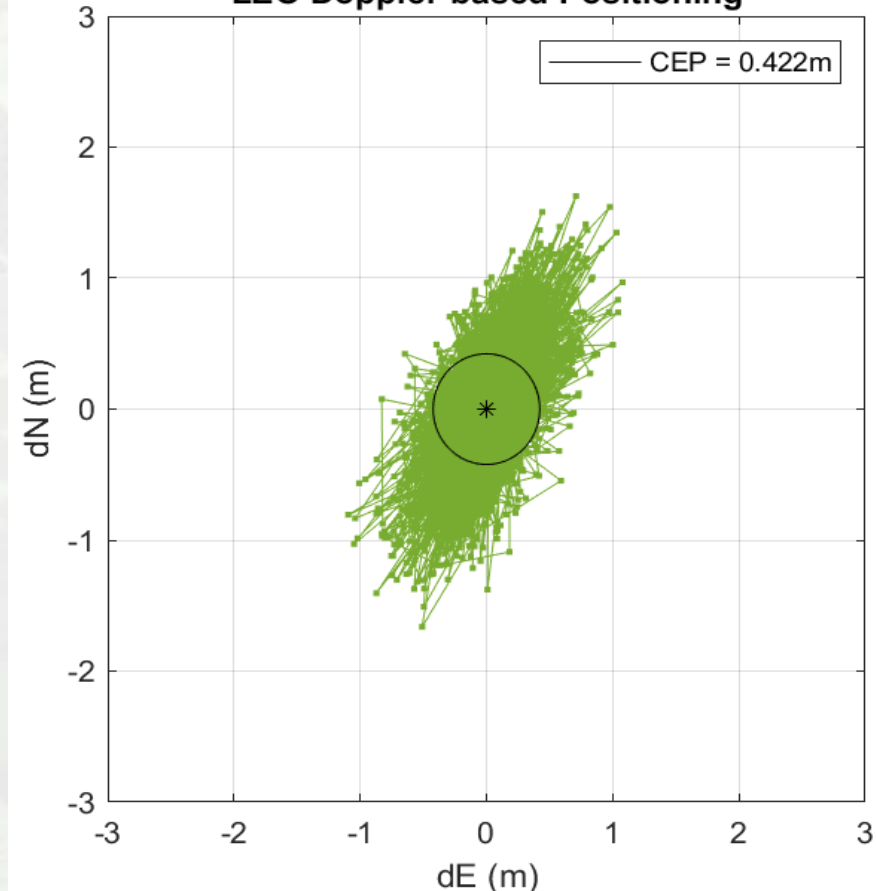


#3 Simulation NavIC Code + LEO Doppler-based Navigation Solution

- Combination of NavIC Code + OneWeb Doppler observations
- On par with NavIC only code solution

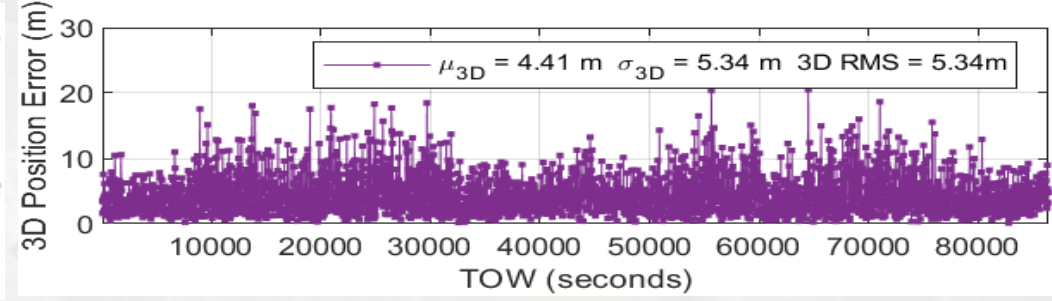
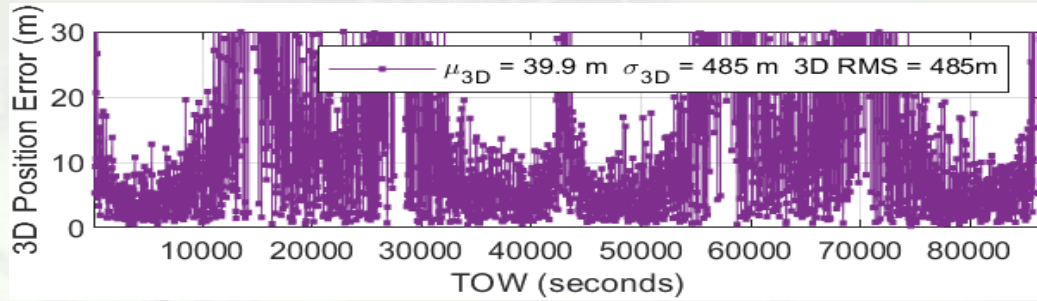


2D Plot of Position Error in Combined NavIC Pseudorange LEO Doppler-based Positioning

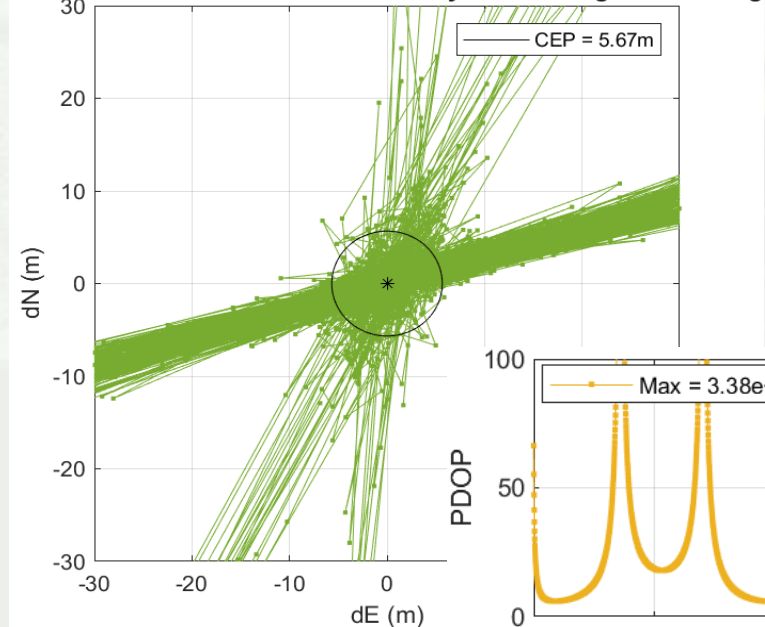


#3 Re-run Simulation with 4 NavIC satellites + LEO Doppler – Indoor Scenario

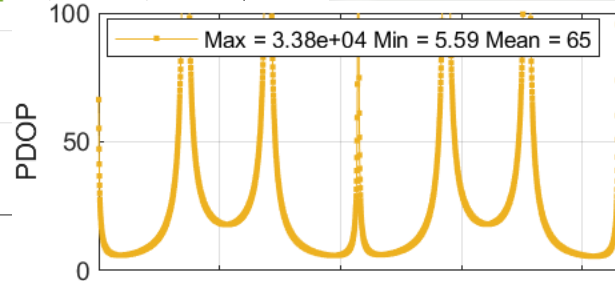
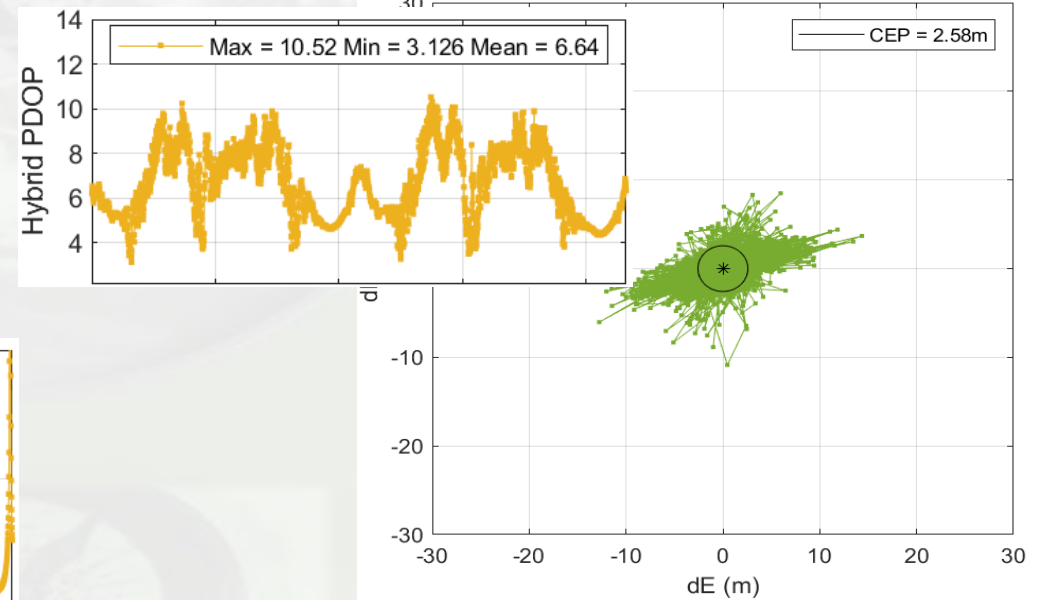
- Limited code observations + OneWeb Doppler observations



2D Plot of Position Error in NavIC Only Pseudorange Positioning

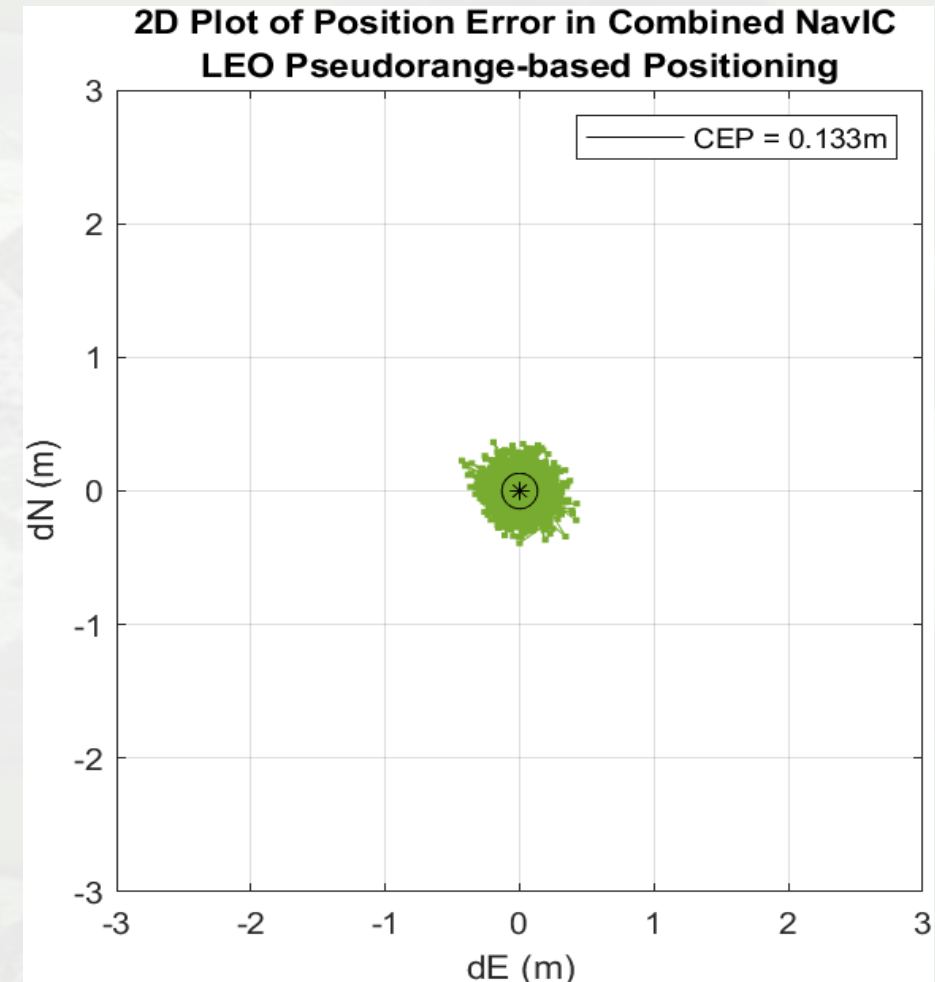
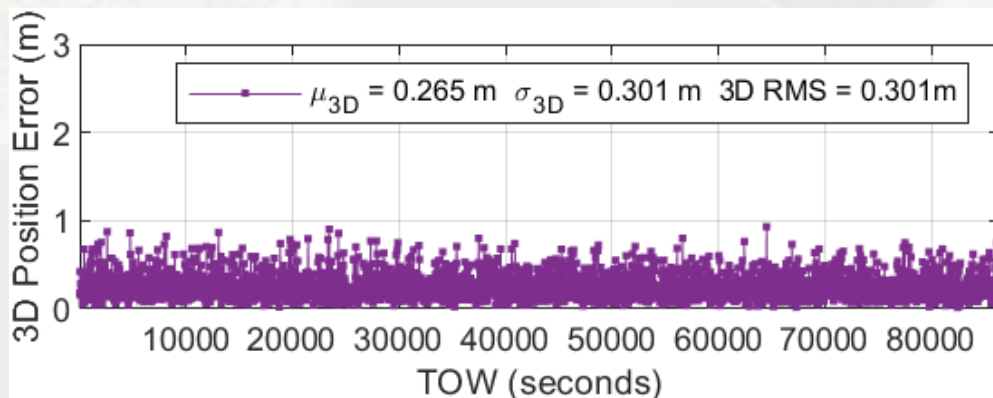
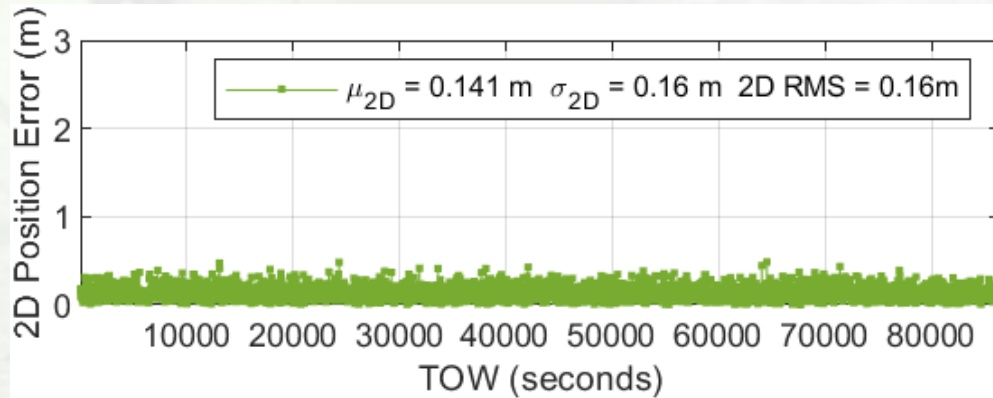


2D Plot of Position Error in Combined NavIC Pseudorange + LEO Doppler-based Positioning



#4 Simulation NavIC + LEO Code-based Navigation Solution

- Assumption – code observations are available from OneWeb
- Improved solution



Summary

- Doppler-DOP of LEO Doppler-based positioning is very large and ranges between 300 to 400; position accuracy is poor
- When LEO Doppler observations are processed along with NavIC code observations, hybrid solution is on par with NavIC only code solution
- Contribution of Doppler observations in navigation solution is small when Code observations are available
- Standalone Doppler-based solution is recommended in GNSS-denied environment
- Combined code observations from NavIC and LEO provide improvised solution
- LEO constellations can compliment NavIC positioning



Thank you