Doppler Positioning with LEO Satellites and Combination with NavIC

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Outline

• 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

<table>
<thead>
<tr>
<th>Details*</th>
<th>Iridium NEXT**</th>
<th>OneWeb**</th>
<th>Starlink**</th>
<th>Kupier**</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Satellites</td>
<td>75</td>
<td>720</td>
<td>~3900 (April 2023)</td>
<td>3,236</td>
</tr>
<tr>
<td>Services</td>
<td>Resilient Timing (STL) by Satelles</td>
<td>Broadband</td>
<td>Broadband</td>
<td>Broadband</td>
</tr>
</tbody>
</table>

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

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LEO & Doppler Observations

- 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
Simulations and Types of Positioning

• 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

- NaviC Only Pseudorange-based DOP
- LEO Doppler-based DOP
- NaviC Pseudorange + LEO Doppler-based Hybrid DOP
- NaviC+LEO Pseudorange-based Combined DOP
#1 Simulation - NavIC only Code-based solution

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

![Graph showing 2D and 3D position error with no biases and a CEP of 0.422m]

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• 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

\[ \mu_{2D} = 0.48 \text{ m} \quad \sigma_{2D} = 0.565 \text{ m} \quad 2D \text{ RMS} = 0.565\text{m} \]

\[ \mu_{3D} = 0.828 \text{ m} \quad \sigma_{3D} = 0.949 \text{ m} \quad 3D \text{ RMS} = 0.949\text{m} \]

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

CEP = 0.422m
#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

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#4 Simulation NavIC + LEO Code-based Navigation Solution

- Assumption – code observations are available from OneWeb
- Improvised 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