Collaborative Opportunistic Navigation
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**The Problem**
GNSS signals are insufficient for anytime, anywhere navigation, particularly in deep urban canyons, indoors, and environments experiencing intentional jamming, as they attenuate \( \sim 30-50 \text{ dB} \).

**Solution: Exploit SOPs**
Ambient signals of opportunity (SOPs) may enhance and assist conventional navigation techniques.

**Potential SOPs**
- **GNSS**: GPS, GLONASS, Galileo
- **Other SVs**: Iridium
- **Cell**: CDMA, GSM, 4G LTE
- **Misc.**: Wi-Fi, HDTV, AM, FM

**SOP Comparison**

<table>
<thead>
<tr>
<th>SOP</th>
<th>Signal power (dBW)</th>
<th>Freq. stability</th>
<th>Tx position known?</th>
<th>Tx timing offset known?</th>
</tr>
</thead>
<tbody>
<tr>
<td>GNSS</td>
<td>(~-150)</td>
<td>(10^{-12})</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>CDMA</td>
<td>(~-110)</td>
<td>(10^{-10} - 10^{-11})</td>
<td>Sometimes</td>
<td>Rough sync, (~\mu\text{sec})</td>
</tr>
<tr>
<td>Iridium</td>
<td>(~-130)</td>
<td>(10^{-10} - 10^{-11})</td>
<td>(~100\text{m})</td>
<td>✓</td>
</tr>
</tbody>
</table>

**State Definition**
State:
\[
\begin{align*}
x_r &= \begin{bmatrix} r_r^T, \dot{r}_r, \delta r_r, \gamma_{0,r,s_1}, \ldots, N_{r,s_m} \end{bmatrix}^T \\
x_s &= \begin{bmatrix} r_s^T, \dot{r}_s, \delta r_s, \psi_{0,i}, \ldots \end{bmatrix}^T, \ i = 1,2,\ldots, m
\end{align*}
\]

**Observability Analysis**
**Theorem:** A collaborative opportunistic navigation environment consisting of \( n \) receivers with velocity random walk dynamics making pseudorange observations on \( m \) stationary SOPs is completely observable if and only if the initial state(s) of at least
- one receiver is fully-known, or
- one receiver is partially-known and one SOP is fully-known, or
- one SOP is fully-known and one SOP is partially-known.

**Simulation Results**
Environment with 1 fully-know SOP and 1 partially-known SOP

**Experimental Results**

**References**