Terrestrial GPS Augmentation with a Metropolitan Beacon System

Presentation to:
National Space-Based Positioning, Navigation, and Timing Advisory Board

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Desired Characteristics

- Terrestrial GPS Augmentation:
  - GPS-like signal structure, but not on, or near L1, L2, L5
  - 3D positioning and time/frequency
  - High reliability, encryption/authentication
  - Coverage: rural, sub-urban, urban, indoor (high yield)
  - Minimal device impact (cell phone/tablet): acceptance
  - Low power, first fix in seconds
  - Passive: no network saturation, privacy
  - Scalable: metropolitan areas / building structures

- Supports Applications:
  - Consumer, E-911, First responder (blue force tracking etc.), Asset tracking, Time/Frequency Reference
The E-911 Challenge

- FCC notice of proposed rulemaking (Feb. 2014)
  - Majority of 911 calls come from wireless phones
    - CA: from 55.8% in 2007 to 72.7% in 2013
  - Example: Fairfax, VA - September 2013, Up to 47% of wireless 911 calls did not include Phase II location information
- Phase II (by 2019 – outdoor only): latitude and longitude
  - Network: 100 m (67%), 300 m (90%)
  - Handset: 50 m (67%), 150 m (90%)
- NPRM Accuracy: outdoor and indoor
  - Horizontal: 50 m (67% 2 yrs, 80%, 5 yrs)
  - Vertical: 3 m (67% 3 yrs, 80%, 5 yrs)
- Comment cycle closes Dec 17th, 2014
GPS Indoor

Indoor, 2nd floor of a 4-story steel/concrete building

• Key: oscillator, antenna, IMU, vector tracking, lots of processing power
• Works, but somewhat of an integration challenge
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Trade Space

- Frequency:
  - Stay out of L-Band (1-2 GHz)
  - Nice if within cell phone bands (824-960 MHz, 1.7-2.7 GHz)
- Bandwidth: at least 2 MHz
  - Multipath, C/A Code
- Geometry
- Power/Coverage
  - Cellular network design
  - Time-division multiple access for near-far mitigation
Urban Propagation

- Hata-Okumura Propagation Model [1]

Spectrum: 919.75 – 927.5 MHz

NextNav M-LMS B&C Block Licenses

- Cover over 93% of US POPs with 8 MHz of spectrum
- Spectrum licenses covering all major U.S. metros
- Spectrum footprint complements GPS
- ~900 sq miles coverage in the SF bay area

M-LMS licenses were auctioned on an EA basis.
# Spectral Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tx transmission type</td>
<td>Spread spectrum, pseudorandom codes (e.g. Gold Code)</td>
</tr>
<tr>
<td>Data</td>
<td>BPSK modulation: nav data bits (encryption/authentication)</td>
</tr>
<tr>
<td>RF Bandwidth</td>
<td>2.046 MHz</td>
</tr>
<tr>
<td>Tx center frequency</td>
<td>920.773 MHz to 926.227 MHz (tunable)</td>
</tr>
<tr>
<td>Tx power</td>
<td>30 W ERP (vertical polarization)</td>
</tr>
</tbody>
</table>

System Characteristics

- Fully redundant Master/Slave (per transmitter)
- Battery backup (per transmitter)
- Multiple transmit sites (system level redundancy)
- Current time/frequency performance:
  - GPS/Rubidium timing loop ($\approx 10^{-11}$) for GPS smoothing, hold-over (incl. Rb coasting), and fine timing
  - Common-view GPS time transfer between MBS beacons (2.5 ns)
- Under development (no GPS dependency):
  - Two-Way Time Transfer (TWTT) between beacons
  - Synchronization with USNO

\[
\begin{align*}
t_{R,B} &= t_{T,B} + cR = t_{T,A} - \Delta t_{A,B} + cR \\
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\end{align*}
\]
# Timing/Frequency Performance

<table>
<thead>
<tr>
<th>Mode</th>
<th>Rx Timing Performance¹</th>
<th>Frequency Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS/Rb timing loop (Self-timed)</td>
<td>20-50 ns</td>
<td>Approaches Stratum-1 level (10⁻¹¹)</td>
</tr>
<tr>
<td>Tuned Rb Coasting (GPS Outage)</td>
<td>&lt; 100 ns (1 hr)</td>
<td>Stratum-1 level up to 24 hrs, Stratum-2 (10⁻¹⁰) up to 1 month</td>
</tr>
<tr>
<td>TWTT Sync with USNO, and Rb in a timing loop (backup to GPS disciplining)</td>
<td>20-50 ns</td>
<td>Approaches Stratum-1 level</td>
</tr>
<tr>
<td>TWTT between beacons (GPS Free; Rb core clock)</td>
<td>10-30 ns</td>
<td>Approaches Stratum-1 level</td>
</tr>
</tbody>
</table>

¹ This column illustrates an aggregate MBS timing receiver performance, deep indoors and under heavy multipath conditions. Beacons synchronized within 2.5 ns
Metropolitan Beacon System Performance

Communications Safety, Reliability and Interoperability Council ("CSRIC") Sponsored Blind Trials – 4Q12

Urban
San Francisco Financial District

Suburban
Santa Clara County

Rural
San Benito County

NEXTNAV

OHIO UNIVERSITY
Horizontal Positioning Performance

All Fixes 2D Error

Point positioning (cold start fix)

50 m (80%)
50 m (67%)

Fraction < Error

2D Error (m)

50 m

NN Rev 2, 99% Yield, 2D error = 39m/72m (67/90%)
NN Rev 1, 96% Yield, 2D error = 52m/99m (67/90%)

Fraction < Error

2D Error (m)
Vertical Positioning Performance

Vertical CDF (Rev 2 test Results)

- 3 m (80%)
- 3 m (67%)

Point positioning (cold start fix)

Note: building image is illustrative only, and does not represent an actual floor plan.
Persistently better than 10 m Accuracy

- E911 scenario is extremely limited (e.g.: Warm/Cold Start fix)
- In commercial and police/fire tracking additional benefits can be gained by Hot Start, Kalman filtering etc.
- This chart depicts tracking performance based on MBS systems – no additional signals or sensors (e.g. IMU, GPS etc.)
- Effectively provides “Room/Store-level/floor-level” context

Walking User Experience: http://vimeo.com/90489380 password: WalkingDemo1
NextNav Local System Performance

Optimized for campus, mall, warehouse-like areas

CDF of 2D Position
Accuracy in m

50%/68%/90%

Rev 1
6m / 7m / 10m

Rev 2
4m / 5m / 7m

Rev 1
Rev 2
Conclusions

- GPS-like approach for user device integration
- Cellular-like approach for urban signal penetration