Multipath Mitigation Algorithm Results using TOA Beacons for Integrated Indoor Navigation

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Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18
Cognitive RadioNavigation Concept

CRN-SDRs use GPS waveform to provide precise “virtual clock” to all Reference units, which enables combination of SoOP and Beacon signals for Nav.
Use of SDR Beacons in RSN

- SDR Beacons broadcast TOA signal for RF ranging
  - Enables navigation in the absence of GPS and other signals-of-opportunity
- SDR Reference Units provide common time-base
  - Uses GPS waveform to create a precise “virtual clock” to reference SoOP observations
  - Allows multiple signal sources to be combined in a common navigation solution
- SDR Mobile Units demonstrate inertial-aided multipath mitigation
  - 900 MHz TOA waveform with 10.23 Mbps modulation
  - Enhanced MLE algorithm with inertial/clock-aiding for direct/multipath signal resolution
  - Enhanced fault detection and exclusion (FDE) for GPS and beacon measurements
Benefits of a Software Defined Radio (SDR)

- Digital Antenna Element (DAE)
- FPGA Card
- Host Processor

- Multiple Frequencies supported by flexible RF/Digital Transceivers
- Flexible waveform processing using FPGAs
- Software control of SDR configuration and operation
SDR Master Unit Hardware Design

- Novatel GPS-701-GG GPS Antenna
- Digital Antenna Elements (GPS + 900 MHz) Correlator Accelerator Card
- Sony Ericsson GC89 Datalink Card (GSM & 802.11)
- HyperLink RE1905U Antenna

- Hyperlink Technologies HGV-906U 900 MHz Antenna
- PCI/ISA
- PCMCIA Carrier Module
- PCI/ISA
- USB
- Cleware USB-Temp Temperature Sensor
- Vaisala PTB210A Digital Barometer
- RS-232
- IDE
- Digital Logic ADL855PC-728 PC-104 CPU Board
- 2.5 HD
- 12.0 VDC Power Module
900 MHz TOA Broadcast

- Waveform selection
  - CDMA (PRN code modulated)
  - FDMA (Frequency selectable in firmware)
  - TDMA (Slot selected in firmware)

TOA Acknowledge Message broadcast by Pseudolites

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Week, secs</td>
<td>GPS time of week in msecs of first TOA being transmitted</td>
</tr>
<tr>
<td>PRN</td>
<td></td>
<td>ID of PRN code broadcast by pseudolite.</td>
</tr>
<tr>
<td>Signal Period</td>
<td>ms</td>
<td>Interval between TOA ranging signals on RF link (0 means transmission will stop)</td>
</tr>
<tr>
<td>Signal Duration</td>
<td>ms</td>
<td>Duration of TOA ranging signal on 900MHz link</td>
</tr>
<tr>
<td>Signal Freq</td>
<td>MHz</td>
<td>Nominal RF Frequency of TOA ranging signal</td>
</tr>
</tbody>
</table>
SDR Slave Unit Hardware Design

HyperLink RE 1905U
GSM Antenna (if necessary)

Wi-Systems
GPS + 900 MHz Antenna

Antenna Mounting Board

SDR Slave Unit

12V Battery

Honeywell HG1930 IMU
(inside of protective enclosure)

Vaisala PTB210A
Barometer

DC-DC Converter

Mounting board
Under RSN effort, additional functionality was added to the SDR processing to handle beacon and GPS multipath effects.

- MLE-UTC filtering uses inertially aided tracking loops to enable tracking under low power and high multipath conditions.
- GTI-RAIM uses redundant GPS/beacon measurements to perform FDE.
MLE-UTC Filtering Algorithm

Multipath Rake Tracking

Close-In Multipath

UTC Direct Path Aiding

Far-Away Multipath
GTI-RAIM Algorithm

- GI-RAIM was previously used to detect and remove out-of-tolerance GPS faults before they are applied to the blended KF solution
- For RSN, FDE solution was extended to detect and reject TOA errors (GTI-RAIM)
- Approach can also be extended to other SoOP using blended RSN solution
Testing Overview

• 7 beacons operating in TDMA mode
  • 2 second frame length
  • 200ms slot length
  • Broadcasting at ~23 dBm
• 1 backpack-mounted receiver with GPS, TOA, IMU and baro
• 12 indoor survey points
SDR Units in the Field
UTC MLE-Aided Filtering Results

Ranging Error

Test Point 1

Spline-Based Peak Detection

UTC MLE Peak Detection

Pseudorange Error for Test Point 1 (Spline Mode)

Pseudorange Error for Test Point 1 (MLE Mode)
UTC MLE-Aided Filtering Results

Positioning Error

Test Point 1

Spline-Based Peak Detection

UTC MLE Peak Detection

Navigation Results using Spline Mode for Test Point 1

Building Layout

Navigation Results using MLE Mode for Test Point 1

Building Layout
**GTI-RAIM Results**

**Rejected Range Measurements**

*Test Point 8*

Pseudorange Error for Test Point 8 (MLE Mode w/ RAIM)

X denotes rejected measurement
GTI-RAIM Results
Positioning Error
Test Point 8

Without GTI-RAIM

Navigation Results using MLE Mode for Test Point 8
Building Layout

With GTI-RAIM

Navigation Results using MLE Mode w/ RAIM for Test Point 8
Building Layout
UTC MLE + GTI-RAIM

Ranging Error

Test Point 10

Standard Spline without RAIM

UTC MLE with RAIM
UTC MLE + GTI-RAIM

Positioning Error

Test Point 10

Standard Spline without RAIM

Navigation Results using Spline Mode for Test Point 10

Building Layout

UTC MLE with RAIM

Navigation Results using MLE Mode w/ RAIM for Test Point 10

Building Layout
Conclusion

• 900 MHz TOA Assistance
  • Can provide augmented navigation to units operating inside buildings and in urban environments
  • Algorithms developed for use on 900 MHz beacons can be easily adapted to handle other signals of opportunity in indoor and urban environments

• UTC-MLE Tracking
  • Enables direct path tracking under very strong fading conditions and in high multipath environments

• GTI-RAIM
  • Redundant measurements allow for FDE algorithms to prevent multipath interference from corrupting the integrated solution

• Potential Applications
  • Military Operations in Urban Terrain
  • First Responder geolocation