Comparison of Multipath Mitigation Techniques with Consideration of Future Signal Structures

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Overview

- Performance analysis for several multipath mitigation techniques
  - Narrow Correlator™
  - Double Delta Correlator
  - Early/Late Slope Technique (ELS)
  - Early1/Early2 (E1/E2) Tracker
- Consideration of BPSK and BOC signals
  - BPSK(1) representing the current GPS C/A code
  - BOC(2,2) representing one Galileo signal option
- Background/Motivation:
  - Multipath is dominating error source for many GNSS applications
  - Different types of signals will be available in the future

>> how do they perform in a multipath environment?
Introduction

Errors caused by multipath depend on a variety of signal and receiver parameters:

- Signal type/modulation scheme
- Pre-correlation bandwidth
- Pre-correlation filter characteristics
- Chipping rate of code
- Type of discriminator
- Chip spacing $d$ between correlators used for tracking
- Carrier frequency
- Multipath relative amplitude $\alpha$
- Actual number of multipath signals
- Geometric path delay of multipath signal(s)
Signal and Receiver Parameters

<table>
<thead>
<tr>
<th>SIGNAL PARAMETERS</th>
<th>GPS C/A Code</th>
<th>Galileo Signal Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Band</td>
<td>L1</td>
<td>E2-L1-E1</td>
</tr>
<tr>
<td>Center Frequency</td>
<td>1575.42 MHz</td>
<td>1575.42 MHz</td>
</tr>
<tr>
<td>Modulation Scheme</td>
<td>BPSK(1)</td>
<td>BOC(2,2)</td>
</tr>
<tr>
<td>Chipping Rate</td>
<td>1.023 MHz</td>
<td>2.046 MHz</td>
</tr>
<tr>
<td>Chip Length</td>
<td>293.05 m</td>
<td>146.53 m</td>
</tr>
<tr>
<td>Data Rate</td>
<td>50 bit/s</td>
<td>200 bit/s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RECEIVER PARAMETERS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Corr. Bandwidth</td>
<td>32 MHz</td>
</tr>
<tr>
<td>Band Limiting Filter</td>
<td>Ideal Band Pass Filter</td>
</tr>
<tr>
<td>Discriminator</td>
<td>1-Chip Early minus Late</td>
</tr>
</tbody>
</table>

Further assumptions (multipath environment):
- Direct signal always available
- Multipath relative amplitude $\alpha=0.5$
- One multipath signal
- Static environment
Wide (Standard) Correlator (d=1)

Results:
- Maximum multipath error (nearly) identical for both signals
- BOC(2,2) less sensitive to medium-delay multipath
Narrow Correlation Technique

- 2 Correlators with small spacing between early and late code (d < 1)
- NovAtel's Narrow Correlator™: d = 0.1

**Results:**
- Maximum multipath error nearly identical for both signals
- BOC(2,2) less sensitive to long-delay multipath
Correlator

- Basic concept:
  - 5 Correlators (E1,E2,P,L1,L2)
  - Discriminator function: \( D = a(E1 - L1) - b(E2 - L2) \)

- Several discriminator functions can be set up (variation of a and b)
  - Strobe Correlator™ (Ashtech): \( D = 2*(E1 - L1) - (E2 - L2) \)
  - High Resolution Correlator (HRC): \( D = (E1 - L1) - 0.5*(E2 - L2) \)

- Strobe vs. HRC:
  - Different amplitudes
  - Same shape
  >> Same multipath performance expected
HRC discriminator function: \( D = (E1 - L1) - 0.5 \times (E2 - L2) \)

Results:
- Maximum multipath error nearly identical for both signals
- BOC(2,2) sensitive to medium-delay multipath
- BPSK(1) not sensitive to medium-delay multipath
- BOC(2,2) less sensitive to long-delay multipath
**Correlator: Carrier Multipath**

- HRC concept proposes synthesized punctual correlator for carrier tracking
- \( P_{\text{HRC}} = 2P - (E1 + L1) \)

**Results:**

- Maximum multipath error identical for both signals
- BOC(2,2) sensitive to medium-delay multipath
- BPSK(1) not sensitive to medium-delay multipath
- BOC(2,2) less sensitive to long-delay multipath
Early/Late Slope Technique (ELS)

✓ Basic concept:
  • 2 correlator pairs at both sides of the correlation function
  • Determination of slopes $a_1$ and $a_2$
  • Computation of pseudorange correction $T$ by intersecting two first-order polynomials defined by $(K_1,K_2)$ and $(K_3,K_4)$

✓ Introduced to GPS receivers by NovAtel as „Multipath Elimination Technology“ (MET)

$$T = \frac{y_1 - y_2 + \frac{s}{2}(a_1 + a_2)}{a_1 - a_2}$$
Early/Late Slope Technique: Code Multipath

✓ Computation of code error envelopes by comparing the pseudorange correction $T$ with the actual peak location

<table>
<thead>
<tr>
<th>$\tau_1$</th>
<th>$\tau_2$</th>
<th>$\tau_3$</th>
<th>$\tau_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.1</td>
<td>-0.06</td>
<td>0.06</td>
<td>0.1</td>
</tr>
</tbody>
</table>

✓ Remarks:

- Multipath performance strongly depends on actual correlator configuration
- Slight changes of $\tau_1,\ldots,\tau_4$ result in fairly different error envelopes
- impossible to make general statement whether the BPSK(1) or the BOC(2,2) performs better

Multipath error envelopes only valid for given correlator configuration
Early1/Early2 (E1/E2) Tracking

- 2 correlators (E1,E2) located on the early slope of the correlation function
- Amplitudes at E1,E2 are used to compute error function $\Delta R$

Results:
- Multipath errors are zero for path delays greater than $(1+E2)$
- Maximum ranging error of BOC(2,2) much larger than that of BPSK(1)
- BPSK(1) less sensitive to short-delay multipath

Issues:
- Shape of undistorted correlation function must be known ($R=A2/A1$)
- Degraded noise performance (reduced signal power at tracking point)
Summary

Results:

- Double Delta shows the best overall code multipath performance
- E1/E2 Tracker produces large maximum multipath errors (worst multipath performance for short- and medium-delay multipath)
- BOC(2,2) outperforms BPSK(1) for long-delay multipath (path delays > 0.5 chips)