Characterization of multipath propagation effects in GNSS observables

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23.01.2015
Overview

• Introduction

• Multipath effects and signal processing

• Multipath effects in the GNSS observables

• Multipath modelling

• Simulations – Measurement campaign

• Conclusion
Introduction

Multipath errors occurs when the received signal is composed by more than the direct component

- Carrier phase error
- Code phase error
- $C/N_0$ amplitude variations
Multipath – Overview

<table>
<thead>
<tr>
<th>Code Measurements</th>
<th>dm-m</th>
<th>Mitigation possible only for long delay MPCs (e.g. &lt; 30 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Up to 100 m</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phase Measurements</th>
<th>cm-mm</th>
<th>Up to 4.5 cm (L1)</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>

Multipath contamination depends on:

- Antenna Location and Environment
- Material Properties of the Reflectors
- Weather Conditions
- Geometry of MPCs
- Antenna Characteristics
- Receiver Characteristics
- Signal Characteristics

- Multipath effects can be considered as an interference problem of GNSS signal with delayed replicas of itself
Tracking a Compound Signal (1)

- **P**: Phase, SNR
- **E-L**: Time delay (code)

**Line-of-Sight**

**Compound**

**Multipath**
E-L Discriminator (code error)

Distorted E-L Discriminator due to one Multipath Component

- **LOS**
- **MPC**
- **Compound**

Tracking Error

\[ \text{e.g. Code Tracking Error} = 0.15 \text{ [chip]} = 45 \text{ [m]} \]
Arctan Discriminator (phase error)

Phase Error: Relative Amplitude vs Relative Phase

Constructive Interference

Destructive Interference

Phase Error [°]

Relative Phase Between LOS and MP Signals [°]
Multipath Effects in Receiver Level (1) (Experimental Set-up)

IF data processing:
- Nord Nav firmware
- Developed matlab-based software receiver modules for C/N₀ estimators and carrier phase tracking
The HRC was implemented only for Phase Tracking

Drawback
- Reduction of Signal Strength (1/20 of the original Peak)
- Tracking Problems
- Phase and Code observation Quality degradation
Multipath Effects in Receiver Level (3) (C/N$_0$ estimation algorithm vs Tracking Parameters)

### Variance Summing estimator (1 hour IF data set)

- $T=1\text{msec}, \text{rate}=0.5\text{ sec}$
- $T=5\text{msec}, \text{rate}=0.5\text{ sec}$
- $T=10\text{msec}, \text{rate}=0.5\text{ sec}$
- $T=1\text{msec}, \text{rate}=4\text{ sec}$
- $T=5\text{msec}, \text{rate}=4\text{ sec}$
- $T=10\text{msec}, \text{rate}=4\text{ sec}$
Multipath Effects in Receiver Level (4) 
(C/N₀ estimation algorithm - Comparison)

- Different noise impact
- Slightly different trends
Multipath Effects in the Observables (1)  
(Sidereal Repeatability – Different Receivers)

- Individual Sidereal Repeatability
- Different trends between different receivers
- Multipath effect repeat after one sidereal day
Multipath Effects in the Observables (2)
(Multipath Characterization of Pseudo-Satellites)

SEA GATE area in Rostock harbor is the marine Galileo test infrastructure consisting of three segments:

1. Nine Pseudolites
2. Two reference stations
3. User Segment

Characterization of the multipath contamination of the reference stations of the SEA GATE environment
Multipath Effects in the Observables (3)  
(Multipath Characterization of Pseudo-Satellites)

- PSL5 and PSL4 show high Multipath contamination
- Afternoon hours multipath effects are not so frequently present in the Data Sets
Multipath Effects in the Observables (4)
(Multipath effects in PPP residuals)
Multipath Effects in the Observables (5) (Indoor Scenario – Experiment set-up)

- Antenna
- RHCP
- LHCP
- Splitter
- Ublox
- IFEN
- RINEX
- IF
- Data Storage
- Ublox Receivers
- Splitters
- Dual Front-end

Ublox Receivers
Splitters
Dual Front-end
Multipath Effects in the Observables (5) (Indoor Scenario – Sidereal rep. of Fadding)

**RHCP: Day1 and Day 2**

C/N₀ on 08/09.2014 for PRN16

**LHCP: Day1 and Day 2**

C/N₀ on 08/09.2014 for PRN16
### RHCP Antenna

<table>
<thead>
<tr>
<th>Weighting</th>
<th>RMS $dX$ [m]</th>
<th>RMS $dY$ [m]</th>
<th>RMS $dZ$ [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identity</td>
<td>10.91</td>
<td>9.98</td>
<td>19.94</td>
</tr>
<tr>
<td>Elevation</td>
<td>12.17</td>
<td>12.00</td>
<td>20.60</td>
</tr>
<tr>
<td>Elevation $(\cos)$</td>
<td>15.08</td>
<td>14.25</td>
<td>24.25</td>
</tr>
<tr>
<td>Elevation $(\cos^2)$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C/N_0$</td>
<td>10.06</td>
<td>9.25</td>
<td>18.49</td>
</tr>
</tbody>
</table>

### LHCP Antenna

<table>
<thead>
<tr>
<th>Weighting</th>
<th>RMS $dX$ [m]</th>
<th>RMS $dY$ [m]</th>
<th>RMS $dZ$ [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identity</td>
<td>10.89</td>
<td>9.59</td>
<td>17.46</td>
</tr>
<tr>
<td>Elevation</td>
<td>12.74</td>
<td>10.20</td>
<td>19.86</td>
</tr>
<tr>
<td>Elevation $(\cos)$</td>
<td>16.57</td>
<td>11.07</td>
<td>24.70</td>
</tr>
<tr>
<td>Elevation $(\cos^2)$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C/N_0$</td>
<td>10.23</td>
<td>9.06</td>
<td>15.97</td>
</tr>
</tbody>
</table>
Part 1: Outlook (GNSS Signal Processing)

• Signal Processing:
  1. **Modification of the tracking modules** of the Borre et.al. Software receiver in order to correlate longer signal snapshot (e.g. 2, 5, 10, 20 ms).
  2. Implementation of **different discriminators** for carrier-phase tracking.
  3. Implementation of **advanced correlators** (HRC) for multipath mitigation purposes.
  4. Implementation of different **C/N₀ estimation algorithms** in software receiver.

• Results Showed:
  1. Filter out long delay MPCs
  2. No improvement for short delay MPCs (< 30 m)
  3. Increase processing capacity (HRC)
  4. Decrease signal quality (HRC)
  5. Power Ratio estimator and Variance Summing estimator C/N₀ algorithms give noisier observations
  6. Usage of longer signal snapshots results in better signal quality
  7. Longer average periods filter out noise
Part 1: Outlook (GNSS Data Analysis)

**Data Analysis:**
1. Multipath effects can be identified in $C/N_0$, DD (of a short baseline), residuals.
2. Calculate the exact sidereal repetability time of individuals PRNs and of multipath effects ($C/N_0$).
3. Residual analysis of PSL observations and characterization of SEA GATE environment in terms of multipath contamination ($C1$).
4. PPP residual analysis of a reference station in Wettzell (L1 in progress...).
5. Characterization of indoor fading behavior with dual polarized antenna and the use of different weighting schemes (Positioning).

**Results Showed:**
1. Different receivers same multipath contamination (short delay multipath).
2. Repeatability of multipath effects due to the repetability of the satellite orbits.
3. Each satellite has a unique repetition period (few seconds difference).
4. Obstructions of the line-of-sight at several epoch in the region enclosed by RS1, RS2, PSL 4 and PSL 5 (a lot of moving reflectors in the region!).
5. Afternoon hours (e.g. 18:00 local time) the before mentioned effects are not so frequently present in the data sets.
6. Fading behavior from the different antenna outputs is uncorrelated.
7. Potential use for different antenna diversity schemes (e.g. polarization diversity) with different combining algorithms.
8. $C/N_0$ based weighting improves the indoor positioning accuracy.
Part 2

Development of a Generalized Multipath Model
Multipath errors in the Observation domains are characterized as functions of:

- Multipath **Relative Phase** w.r.t. LOS $\Delta \Phi$ *(geometry)*
- Multipath **Relative Amplitude** w.r.t. LOS $\alpha$ *(Not directly accessible)*
Multipath Modeling: GNSS Signal Amplitude

Receiving Antenna

LOS Signal: RHCP

Reflected Signal: Partially RHCP Partially LHCP
Multipath Modeling - Simulations (1)  
(Phase error)

- **Geometry** (Height above the Reflector)
- **Carrier frequency**
- **Reflector** (Material Properties)
- **Antenna** (Gain Pattern)
Multipath Modeling - Simulations (2) (Phase error)

Phase error for the different GNSS frequencies

- Geometry (Height above the Reflector)
- **Carrier frequency**
- Reflector (Material Properties)
- Antenna (Gain Pattern)
Multipath Modeling - Simulations (3) (Phase error)

Phase Error for the Different Reflectors

- Geometry (Height above the Reflector)
- Carrier frequency
- **Reflector (Material Properties)**
- Antenna (Gain Pattern)
Multipath Modeling - Simulations (4) (Phase error – Relative Amplitude)

- Geometry (Height above the Reflector)
- Carrier frequency
- Reflector (Material Properties)
- Antenna (Gain Pattern)
Multipath Modeling - Simulations (5)
(Phase error)

Phase Error for the Different Antennas

- Geometry (Height above the Reflector)
- Carrier frequency
- Reflector (Material Properties)
- Antenna (Gain Pattern)
PTB antenna test facility in Braunschweig

- Antennas with different height
- Antennas spaced 21.3 m
- Observational period about 7 hours
- Cut-off angle of 0°
- Data rate was 1 Hz.
- One pair of AX1202GG Leica antennas
- One pair LEICA GRX1200+GNSS receivers.
Multipath Modeling
C/N₀ – Observed vs Simulated

PRN 12: Observed C/N₀ vs Simulated Signal Amplitude (A2 antenna)

PRN 14: Observed C/N₀ vs Simulated Signal Amplitude (A1 antenna)
Multipath Modeling

DD Phase error – Observed vs Simulated

[Graphs showing phase error for different configurations and time periods]

Phase DD - Simulated VS Observed

[Graph comparing simulated and observed phase differences]

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Multipath Modeling
Horizontal vs Tilted Reflector

Phase DD - Simulated VS Observed

PRN12 - PRN14: Observed Phase-DD vs Simulated Phase-error-DD
Multipath Modeling
Observed vs Simulated phase-DD

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Thank You!