On
GNSS Station Calibration
of
Antenna Near-Field Effects
in
RTK-Networks

Gerhard Wübbena, Martin Schmitz

Geo++® GmbH
30827 Garbsen
Germany

www.geopp.com
Overview

- Motivation
- Near-Field Effects / Near-Field Multipath
  - Cause and Impact
  - Robot Calibration
- Station Dependent Errors
  - Separation of Near-Field and Far-Field Effects
  - Different Treatments
- Near-Field Calibration (In-Situ) of single sites - CaNF
  - Principle, Setup, Results
- Near-Field Compensation in RTK-Networks - CoNF
- Summary/Outlook
Motivation

- **Issue of near-field (NF) effects** is of increasing importance and interest in GNSS applications

- **more and more problems** due to the NF issue become obvious
  - antenna changes cause significant jumps in coordinate time series
  - non-modeled NF effects cause biased estimates for other parameters in a GNSS application
    - tropospheric zenith delay, tropospheric gradients,
    - coordinates
    - carrier phase ambiguities
    - ...
  - and therefore reduce the performance (accuracy, availability, reliability) of the GNSS applications
Motivation

- Strategies/methods for determination/correction/handling of NF effects are required to
- improve the accuracy, availability and reliability of GNSS applications
  - permanent reference stations, coordinate time series
  - RTK networks – service performance and integrity
  - precise height determination using GNSS methods
  - kinematic platforms (strong NF effects of car roofs, in-situ calibration)
  - ...

Near-Field Effects: Cause

- antenna near-field depends on
  - antenna type
    (plus radome construction, ...)
  - mount/setup
    (tripod, tribrach, adaption, ...)
  - station environment
    (pillar, roof, ...)
  - weather conditions
    (reflecting coefficient, snow, ...)

- effect on signals due to
  - reflection
  - diffraction
  - imaging / electro-magnetic inter-action
Near-Field Multipath: Theoretical Impact

model assumption: horizontal reflector

- pillar/pier setup
  - high “spatial” wavelength
  - effect in all elevation areas
  - non-zero average
  - systematic coordinate errors

- tripod setup
  - low “spatial” wavelength
  - effect in all elevation areas
  - zero average over short observation times
IGS Warning/Recommendation (Jim Ray, NGS, 2008)

Thank You

for mounting
your antennas
away from
reflecting surfaces!

Station Dependent Errors

- Geo++ philosophy: separation of individual error components
- PCV and multipath effects are most important station dependent errors
  \[ dS = PCV + MP \]
  - PCV => absolute GNSS antenna calibration
  - multipath => difficult to calibrate and model highly variable total MP in an operational procedure

- Strategy: separation of near-field (NF) and far-field (FF) multipath
  \[ dS = PCV + MP_{NF} + MP_{FF} \]
- Methods to determine and mitigate NF effects

In-Situ Station Calibration
Near-Field Multipath: Robot Calibration

- determination with precise robot calibration
  - standard deviation 0.2 bis 0.4 mm
  - repeatability 1 mm, except close to horizon
- representative near-field environment required
- constant geometric relation antenna/near-field despite movements of antenna
- calibration provides PCV + MPNF
- separation obtained through difference of calibration with/without near-field environment and antenna

PCV  phase center offsets and variations
MP  multipath
Near-Field Multipath: eg Impact on DM-Type Chokering Antenna

- ASH700936D_M
- reconstruction head of pillar/tribrach
- $\varnothing$ 19cm/$\Delta$ Zeiss
- difference L0 PCV against regular calibration
  - 10-30° elevation
    mean ca. 2 mm
    maximum 7 mm
  - 40-70° elevation
    mean ca. 2 mm
    maximum 3 mm
  - impact in range domain!

L0 ionospheric free linear combination
Near-Field Multipath: eg Impact on DM-Type Chokering Antenna

- ASH700936D_M
- reconstruction head of pillar/tribrach
- 30x30 cm/Δ Zeiss
- difference L0 PCV against regular calibration
  - 10-30° elevation
    mean ca. 2 mm
    maximum 6 mm
  - 40-70° elevation
    mean ca. 4 mm
    maximum 5 mm
  - impact in range domain!
Real Life Example from RTK Networking

- TPSPG_A1 GNSS antenna
- 10 cm prism spacer and special construction with two ground planes ca. ∅ 14 cm
- target device for classical surveying
- L1 PCV difference against regular calibration
  - 10-30° elevation
    mean ca. 3 mm maximum 6 mm
  - 40-70° elevation
    mean ca. 1 mm maximum 2 mm
Real Life Example from RTK Networking

- TPSPG_A1 GNSS antenna
- 10 cm prism spacer and special construction with two ground planes ca. $\varnothing$ 14 cm
- target device for classical surveying
- L2 PCV difference against regular calibration
  - 10-30° elevation
    - mean ca. 4 mm
    - maximum 8 mm
  - 40-70° Elevation
    - mean ca. 1 mm
    - maximum 4 mm
• amplification for L0 PCV
• L0 PCV differences against
  - 10-30° elevation maximum -18 mm
  - 40-70° elevation maximum +5 mm
• repeatability of five antenna constructions ca. 4 mm
• also individual PCV and near-field components of antennas present
Real Life Example from RTK Networking

- Kadaster, The Netherlands
- NETPOS RTK Network (31 stations)
- 81 control points of Dutch network
- 10 RTK measurements with 10 initializations each time
- without near-field correction
  - time and spatial dependent height errors
  - mean of systematic height error is 31 mm (81 points)
- with near-field correction
  - free of systematic errors
  - mean height difference is -2 mm (49 points)

results and graphic have been kindly provided by Kadaster, The Netherlands
## Station Dependent Errors: Different Treatments

<table>
<thead>
<tr>
<th>Error</th>
<th>Characteristic</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna</td>
<td>PCV</td>
<td>calibration of PCV using robot</td>
</tr>
<tr>
<td>Multipath</td>
<td>MP\textsubscript{near-field}</td>
<td>calibration of near-field effects using robot/in-situ station calibration</td>
</tr>
<tr>
<td></td>
<td>MP\textsubscript{far-field}</td>
<td>averaging over time, absolute station calibration or weighting (CN0)</td>
</tr>
<tr>
<td>Station</td>
<td>Uncertainty</td>
<td>analysis of time series</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>stable underground, setup, monumentation</td>
<td></td>
</tr>
</tbody>
</table>

CN0 carrier-to-noise
## Determining NF effects of a Reference Station

<table>
<thead>
<tr>
<th>Approach</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>explicit determination</td>
<td>robot calibration (since 2002)</td>
</tr>
<tr>
<td>noisifying multipath</td>
<td>station calibration using robot (Böder et al. 2001)</td>
</tr>
<tr>
<td>averaging multipath</td>
<td>multiple station setup (Wübben et al. 2006)</td>
</tr>
<tr>
<td>determine near-field correction and weighting from</td>
<td>in situ station calibration with calibrated, multipath free equipment</td>
</tr>
<tr>
<td>L1 &amp; L2 residuals</td>
<td>(method 1) - CaNF</td>
</tr>
<tr>
<td>determine near-field correction and weighting from</td>
<td>in situ station calibration/ NF compensation within a network of</td>
</tr>
<tr>
<td>L0 residuals in redundant setups</td>
<td>GNSS reference stations - CoNF</td>
</tr>
<tr>
<td>combination of approaches</td>
<td>use of some in situ calibrated stations (method 4) and apply it to</td>
</tr>
<tr>
<td></td>
<td>constrain method 5 - CNF</td>
</tr>
</tbody>
</table>
In-Situ Site Calibration (CaNF): Near-Field Free Station

- individual absolute GNSS antenna calibration
- optimal control of near-field effect required
  - mock-up of top robot and mount
  - best approximation of all errors (near-field and PCV of antenna)

(top of robot with mount)
In-Situ Site-Calibration (CaNF): Near-Field Free Station

- mock-up of antenna's robot calibration  
  - no near-field multipath
- high and slight setup on a pole (~ 3 m)  
  - reducing far-field multipath
- short distances  
  - no impact from atmospheric or orbit errors
- setup and system design  
  - transportable  
  - flexible  
  - scalable  
  - easy to use  
  - ...
In-Situ Site Calibration (CaNF): Setup

- near-field free temporary stations
- redundant setup with three stations (or more)
- stations must cover GNSS visibility of reference stations
- sophisticated GNSS receivers with coupled clocks
In-Situ Site Calibration (CaNF): Setup

- Reference stations to be calibrated
- Original receiver substituted through in-situ calibration system receiver using antenna splitter
- Coupled clock with NF-free stations
- 1 Hz data rate
- 0° cut-off
- At least 24 h data
- 9 days for complete GLONASS calibration
In-Situ Site Calibration (CaNF): Reference Stations

- experiment on Geo++ roof
- reference station on roof top (1000/1001)
  - close objects
  - flat reflectors
  - remote reflectors
- reference station on pillar (0007)
  - standard setup
  - pillar top is reflector
  - remote reflectors
In-Situ Site Calibration: Residual Analysis

- 24h doy 282-283, 2009 reference station (roof top, 1000/1001)
  - GPS L0 residuals shown
  - basically no obstructions
  - prominent band in N (280°-80°) up to ~10°-15° elevation
  - up to 4 cm residual changes over small elevation range
In-Situ Site Calibration: Residual Analysis

- 24h doy 286-287, 2009 reference station (pillar, 0007)
- GPS L0 residuals shown
- obstructions in W (building) and NE (45°-90°, tree)
- alternating pattern reaching 30° elevation over complete azimuth range
- up to 2 ... 4 cm over small elevation range
In-Situ Calibration: Applying Correction/Weighting

- static GPS L0 processing with troposphere estimation
- standard approach and with in-situ correction/weighting applied
- difference to reference coordinates (horizontal GNSS, leveled height*)

* to be checked!
CoNF – Compensation of Near-Field

- Compensation of Near-Field for all network stations
  - utilizes redundancy in GNSS networks
  - determines the near-field effect of all reference stations in a network
  - derives corrections and weighting schemes from non-differenced ionospheric free signal L0 residuals
  - L1/L2/L5 not fully accessible due to non-distinguishable ionospheric effects
  - elevation-azimuth dependent model
CoNF: Network

- GREF network
- 20 reference stations
- automatic procedure to estimate correction and weighting
- automatic application of correction and weighting
CoNF: Residual Analysis

- iterative estimation from GREF network
- several days, 2011 reference station GOET
- GPS L0 residuals shown
- basically no obstructions
- prominent band in EW up to ~30°-60° elevation
- significant systematic residual changes
CoNF: Residual Analysis

- iterative estimation from GREF network
- several days, 2011 reference station GOET
- GLO L0 residuals shown (frequency independent)
- basically no obstructions
- prominent band in EW up to ~30°-60° elevation
- significant systematic residual changes
CoNF: Residual Analysis

- iterative estimation from GREF network
- several days, 2011 reference station GOET
- GPS C1 residuals shown
- basically no obstructions
CoNF: Residual Analysis

- iterative estimation from GREF network
- several days, 2011 reference station HUEG
- GPS L0 residuals shown
- basically no obstructions
- roof visible in plot
CoNF: Residual Analysis

- Iterative estimation from GREF network
- Several days, 2011 reference station HUEG
- GLO L0 residuals shown (frequency independent)
- Basically no obstructions
- Roof visible in plot
CoNF: Residual Analysis

- iterative estimation from GREF network
- several days, 2011 reference station HUEG
- GPS C1 residuals shown
- basically no obstructions
CNF – Calibration + Compensation of Near-Field

- Determination of NF corrections and weighting for all network stations and original signals
  - CaNF calibrations for some selected sites in a network
  - Constraining CoNF with results from CaNF
  - Separation of original signals (L1/L2/L5) instead of ionospheric free signal L0 becomes possible through appropriate ionospheric modelling
  - L1/L2/L5 corrections and weighing schemes for all network sites
Summary CaNF

CaNF (Calibration of Near-Field) of one single site

Determines the near-field and to some degree also the far-field multipath of one single site by deriving corrections from residuals for original signals L1/L2.

Near-Field effects

... based on robot-calibrated equipment and near-field free setup.

Calibrated Near-Field effects

L1 / L2 (single sites)
**CoNF (Compensation of Near-Field)** for all network stations

Determines the near-field for all reference stations in a network by deriving corrections from residuals for ionospheric free signal $L_0$. 

- Near-field effects
- Compensated Near-Field effects
- $L_0$ (for all sites)
Summary CNF

CNF = CaNF + CoNF (Calibration + Compensation of Near-Field)

near-field effects

L1 / L2 (for all sites)

Corrected Near-Field effects
Verification Network (7 RS, Rover: HOFB, 5 Min. Solutions)
Differences to Mean

Without EAR correction

- diff Horizontal
- diff Height
Differences to Mean

With EAR correction

10.10.2011, ©Geo++ GmbH
Summary/Outlook

- **NF** effects can significantly reduce performance of GNSS applications
- **in-situ NF calibration/compensation models** have been developed
  - combined approach using
    - robot calibration to obtain NF-free equipment
    - single site calibration utilizing NF free equipment (CaNF)
    - residual analysis in redundant GNSS CORS networks to compensate NF effects (CoNF)
    - combination of CaNF and CoNF to calibrate all network stations
  - NF correction and weighting models are obtained for all stations and signals
- **Method is ready for operational use**
thank you for your attention
References


An Almost Philosophical Question ...

- obviously there are systematic errors through MP_{near-field}

Is it possible to determine GNSS heights without any systematic error?

- no, without considering MP_{near-field}
- yes, with taking MP_{near-field} into account
  - with absolute MP_{near-field} correction
    heights are free of systematic errors

- recommendation
  - analysis and assessment of additional strategies
  - avoiding MP_{near-field}