

# GNSS Solutions:

## Network RTK

“GNSS Solutions” is a regular column featuring questions and answers about technical aspects of GNSS. Readers are invited to send their questions to the columnist, **Dr. Mark Petovello**, Department of Geomatics Engineering, University of Calgary, who will find experts to answer them. His e-mail address can be found with his biography below..



**Mark Petovello** is a Professor in the Department of Geomatics Engineering at the University of Calgary. He has been actively involved in many aspects of positioning and navigation since 1997 including GNSS algorithm development, inertial navigation, sensor integration, and software development.

Email: [mark.petovello@ucalgary.ca](mailto:mark.petovello@ucalgary.ca)

## What is the effect of user and CORS height on NRTK performance?

**N**etwork Real Time Kinematic (NRTK) positioning is nowadays a very common practice in many parts of the world. The benefits of NRTK positioning and the details of network products have been previously discussed in this column (see the contribution by Leila Kislig in the July/August 2011 issue of *Inside GNSS*), as has the positioning performance as function of the inter-station distances of the network’s continuously operating reference stations (CORS) (see the contributions by P. Dabove *et alia* in the November/December 2011 issue).

However, because GNSS measurement errors are modelled by the net-

work software, the quality of the differential corrections sent to the rover depends on the ability of the network to estimate errors (mainly the atmospheric ones) at individual stations, as well as the capability to spatially model the errors.

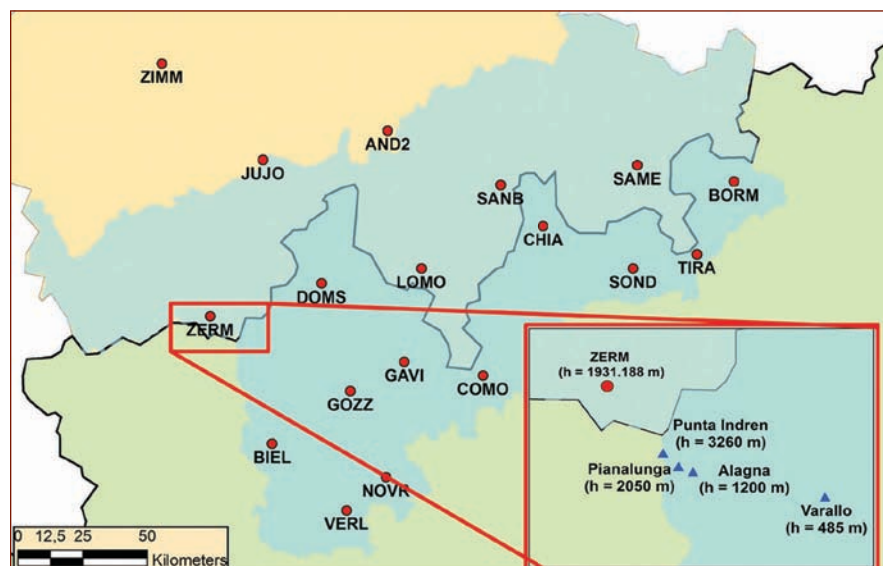
So, what are the CORSs requirements in order to have good NRTK positioning, considering a multi-frequency and multi-constellation receiver, even in areas with extreme changes in altitude? More specifically, can a heterogeneous network in terms of height of CORS sites be used to obtain centimeter-level accuracy for the rover?

We carried out some experiments to answer these questions and present the results in this article.

## The Network

As part of a European Interreg project called HELI-DEM, a network of GNSS CORS stations was established across the Italy/Switzerland border. To carry out our inquiry, we analyzed the current state of permanent stations in the area of study and selected a subset of these existing stations as shown in **Figure 1**.

The network was adjusted according to the EUREF Permanent Net-



**FIGURE 1** Map of the HELI-DEM CORS stations. Black line denotes the Italy/Switzerland border (Italy to the south). Red dots indicate the location of the CORS sites. The magnified area shows the Valsesia Valley containing the test sites (denoted by blue triangles) used for data processing.

# Testing the future of Navigation & Positioning



**NEW!**  
Multi-Frequency,  
Multi-GNSS Record &  
Playback System  
(GSS6425)

**Now including**  
Full BeiDou-2 SIS-ICD  
compliance

## Our Test Systems include:

- M-Code Testing
- SAASM Testing
- Threat Mitigation
- CRPA Testing
- GPS/Inertial
- High Dynamics Testing
- Attitude Control
- GPS Modernization
- Multi-GNSS
- Wi-Fi Positioning
- Consumer Devices.

Spirent Communications plc  
T: +44 1803 546325  
globalsales@spirent.com  
www.spirent.com/positioning

US Government & Defense:  
Spirent Federal Systems Inc.  
T: +1 714 692.6565  
info@spirentfederal.com  
www.spirentfederal.com

**Contact us or more information**

**Invest with Confidence: Experience | Expertise | Accuracy | Support**

Visit the electronic version of Inside GNSS and click on this link to download our popular White Paper - **Effects Of Interference On GNSS Signals**

# Three Great Reasons to Contact Us!

NEW



## CTL3520 GPS Jammer Detector & Locator

- ◆ Detects GPS signal jamming and interference
- ◆ Locates the RF signal source
- ◆ Sensitive: -100dBm in a 20 MHz band around GPS L1



## Geo-iNAV

- ◆ GPS-Aided INS
- ◆ Flexible: L1/L2, RTK, FOG or MEMS IMU



## BD920-W3G Receiver

- ◆ L1/L2 + Communications
- ◆ Multi-band GNSS: GPS/GLONASS
- ◆ GSM, 3G, Bluetooth, Wi-Fi, RTK

Your ONE Source for GNSS Products and Solutions



Woman-Owned Small Business

+1-703-256-8900 • 800-628-0885

www.NavtechGPS.com

## GNSS SOLUTIONS

work (EPN) Processing Instruction for Local Analysis Centres (see EPN Guidelines in the Additional Resources section near the end of this article). For real-time processing of the network data, the Politecnico di Torino has set up a server on which it has installed some network software that performs simultaneous processing of all stations in the network. This provides a better estimation of the global parameters (e.g., ionospheric and tropospheric errors, satellite clock error, ambiguity phase fixing) and increases the reliability of the results compared to the single-station approach.

The CORS network has an average height of about 1,000 meters but the height distribution of stations is highly uneven, varying from as low as 300 meters (Novara) to more than 3,400 meters (Jungfrau Joch — JUJO).

The network software is able to fix the carrier phase ambiguity of the entire network within a few minutes of activation and, apparently, none of the stations are particularly disadvantaged in terms of the percentage of “fixed” satellites. However, the state of the network must also be assessed for measurement quality. In particular, a strong height variability may have an effect on the modeling of atmospheric errors, especially on tropospheric delays — which themselves are highly sensitive to height.

In fact, the sensitivity of GNSS errors with height likely caused the exclusion of the Jungfrau Joch station from the real-time products of the AGNES network described in Kislig’s July/August 2011 article.

## Testing

We undertook a measurement campaign using NRTK products (i.e., differential corrections broadcast, in different ways, by the network software to the rover) on sites with different orthometric heights in order to verify the quality of the network positioning. We decided to choose the Valsesia Valley as the area of study because it has strong geographical variability, allowing for GNSS positions to be computed even at high altitudes, thanks to ski lifts. We conducted four surveys of the same duration but with different station heights and analyzed the positioning accuracy for each.

The chosen test sites were: Varallo Sesia, Alagna Valsesia, Pianalunga and Punta Indren, as shown in the magnified rectangle in Figure 1. We chose these locations to verify the functioning of the CORS network near (but still within) the limit of coverage: the local ski lifts enabled us to go to Punta Indren, a site located approximately one kilometer inside the edge of the network.

The heights of the stations are summarized in **Table 1**.

The rover receiver that we used is able to receive differential corrections in a variety of formats. For the purpose of this work, the format selected requires knowledge of the user’s location (provided to the network using a two-way communication channel) and is similar in concept to the virtual reference station approach described in the July/August

Site	Orthometric height [m]
Varallo	485
Alagna Valsesia	1200
Pianalunga	2050
Punta Indren	3260

TABLE 1. Orthometric height of each test site

2011 “GNSS Solutions.” However, unlike that case, the format used here always provides corrections for real (instead of virtual) reference stations. In this way, the baseline between a master station and the user is measured directly.

Our data analysis compared the coordinates obtained using NRTK with those obtained using post-processing. The reference coordinates of the points indicated with the blue triangle in Figure 1, herein called “true coordinates” for simplicity, are in fact obtained using a commercial GNSS processing software and is based on an adjustment of three static, single-base station processing runs using stations at Zermatt, Biella, and Domodossola. The final accuracy of the true coordinates is a few millimeters.

## Results

Considering the same number of epochs with fixed ambiguity carrier phase for each survey (more than three hours for each point), **Figure 2** shows the horizontal (top) and vertical (bottom) errors versus time. For both plots, the green line denotes the limit of what is considered acceptable positioning accuracy for NRTK applications, namely, 5 centimeters in the horizontal direction and 7.5 centimeters in the vertical direction.

Analyzing the results at the lower altitude point (Varallo Sesia), we noted both a planimetric and vertical shift with respect to the results obtained from the post-processing position. We should point out, however, that the planimetric average remains within the threshold.

Regarding the height, an average shift of about -8 centimeters can be seen in addition to the presence of numerous points outside the 7.5-centimeter threshold.

Also, for the second measurement site (Alagna Valsesia) we can observe a shift in both the planimetric and vertical solutions, even if the amount is less than the previous case. The planimetric average is still acceptable, while the altimetric average is around the value -5 centimeters. This means a slight improvement in the result of positioning relative to the lower altitude receiver.

The third measurement site (Pianalunga) shows the presence of a false fix of the ambiguity phase identifiable in the point cloud that deviates notably from the mean value. If this false fix is not included in the computation, it is possible to affirm an improvement in the average value of the deviations from the previous cases, especially in the vertical component where the cloud of the points has a mean close to zero, except for a few values near -5 centimeters.

# No Travel Funds? We Can Come to You!



## On-Site Courses

- ◆ Select from a comprehensive course list, or customize a course for YOUR specific needs
- ◆ No travel expenses
- ◆ Reduced overhead costs
- ◆ Learn from a company with 29 years of experience
- ◆ Complete course descriptions at [www.NavtechGPS.com](http://www.NavtechGPS.com)
- ◆ Train as a group
- ◆ World-class instructors

## OR, Come to Annapolis, Md.

April 1–4, 2014 (Loews Annapolis Hotel)

### 346: In-Depth GPS/GNSS Operation for Engineers & Technical Professionals

A 4-day version of Course 356, for those who want to save on lodging and overhead, which offers a comprehensive introduction to GPS, system concepts, design, operation, implementation and applications, and a brief overview of DGPS technology. Taught by Dr. Chris Hegarty, MITRE.

### 447: Applied Kalman Filtering with Emphasis on GPS-Aided Systems

An intensive 4-day course on Kalman filtering theory and applications to include linear, extended, unscented, and square root Kalman filters, their practical applications; exposure to 2nd and 3rd order extended Kalman filters, particle filters, integrity monitoring, and more. (See website for details and prerequisites.) Taught by Mr. Michael Vaujin.



#### Contact

Carolyn McDonald  
[cmcdonald@navtechgps.com](mailto:cmcdonald@navtechgps.com)

**NavtechGPS**

Woman-Owned Small Business

+1-703-256-8900 • 800-628-0885

[www.NavtechGPS.com](http://www.NavtechGPS.com)

Despite having requested a network-based correction, analyzing the LOG file from the network software showed that the differential correction broadcast to the rover was instead coming from the nearest reference station (Zermatt, about 20 kilometers away). The same behavior was also observed for the final site (Punta Indren). Nevertheless, the results obtained in these are the best: both the planimetric and the altimetric averages are quite close to zero.

This is very interesting because it allows us to understand the limits of the NRTK positioning, considering the height difference between the rover and the master stations of the cell. In this case, when the rover's height is more than 1,500 meters with respect to the lowest station of the cell, the network software broadcasts corrections derived by the nearest station instead of the requested network correction (it is noted, however, that other network software may or may not exhibit similar behavior).

Unfortunately, unless a user is using the RTCM protocol, it is not currently possible to determine in real-time whether the network is broadcasting corrections interpolated from the network or from the nearest reference station only. To do so requires analyzing the LOG file provided by the network software (if it is available) or evaluating the distance between the positions of the rover and the master station (if it is available during the survey).

We should also note, for the network software used in this study, only two documented possibilities exist with which to obtain a nearest-station correction instead of a network-based correction. The first is if the rover is outside the network, but that is not the case here. The second is if one or more master stations shares only a few fixed satellites with the rover, but this case is excluded here, too.

The take-away from this is that even if the user is aware of the type of corrections being received, in the absence of a proper modeling of atmospheric errors due to the strong variability of the station/user heights, the network software automatically provides the data of nearest station, thus providing acceptable positioning accuracy.

The preliminary results allow us to confirm the good operation, even at high altitudes, of a GNSS heterogeneous network because the network itself is able to detect when the rover is performing positioning at altitudes that are much higher with respect to the average of the considered cell.

Regarding positioning at lower altitudes, the results are slightly worse due to the difficulty encountered by the network in correctly estimating the atmospheric biases on stations with considerable differences in heights.

We can say, therefore, that in the presence of this type of network, it is essential to increase the number of permanent stations regardless of the planimetric inter-station distances between them. Rather, users must ensure that wide variations exist in elevation between nearby permanent stations, in order to limit erroneous estimation of atmospheric biases on GNSS signals. The number of "extra" stations is still an area

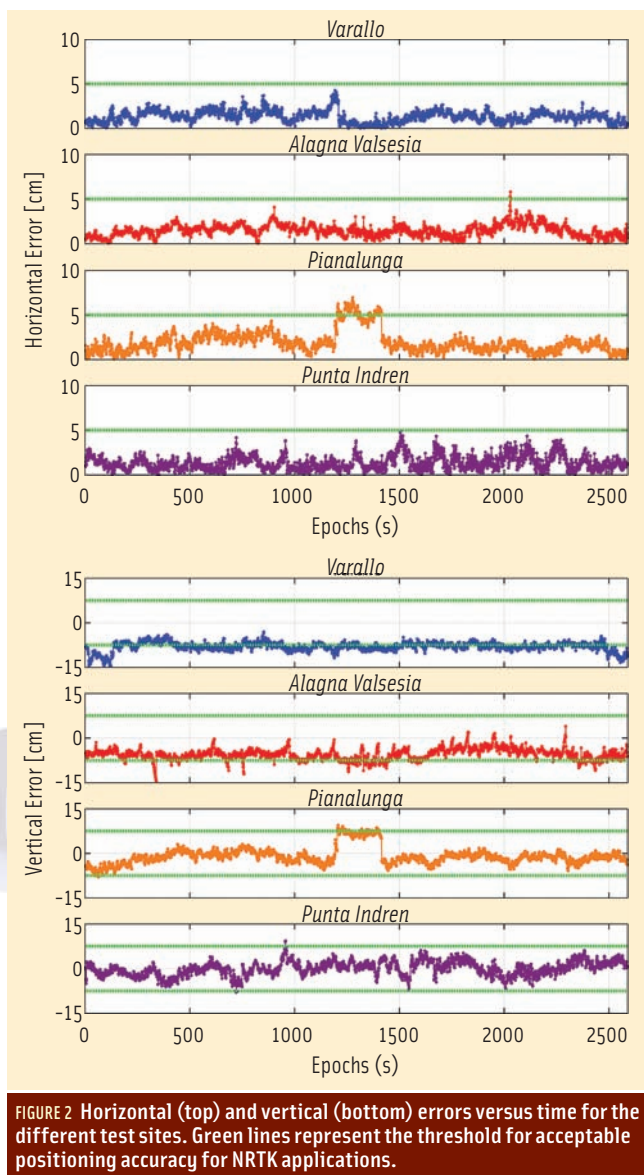


FIGURE 2 Horizontal (top) and vertical (bottom) errors versus time for the different test sites. Green lines represent the threshold for acceptable positioning accuracy for NRTK applications.

of study but is expected to be a function of the vertical inter-station distance between the CORS.

## Acknowledgments

We want to thank swisstopo, Regione Lombardia, and Regione Piemonte for providing the data stream necessary to carry out these tests.

## Manufacturers

The receivers used in the experiments were GX 1230+ GNSS from **Leica Geosystems**, Heerbrugg, Switzerland. Initial adjustment of the network used Bernese GPS Software 5.0 developed at the **Astronomical Institute of the University of Bern**. The network software was GNSS Spider v4.2 distributed by Leica Geosystems, and generation of truth coordinates used Leica Geo Office v.8.0.

# GNSS receivers. Fully equipped to help you make the right decisions

## Galileo compatibility?

Updates with Dual Mode GPS M-Code and Galileo PRS are planned for release

## NAVWAR operation?

Ultra-fast Direct-Y code acquisition and CPRA interface available for the most severe jamming environments

## SAASM capability?

Precise Positioning Services, US GPS directorate-approved, available under US FMS procedure & GPS directorate approved

## Easy upgrade?

Product policy based on a single GRAM-S standard receiver for all air and naval missions

## Civil airspace integration?

Product roadmap including Military Standard Order (MSO) certification



As the operational environment grows more and more complex, Thales delivers a simple solution: the most powerful GNSS suite for all of your applications.

The result of more than 30 years' expertise in the field, the Thales GNSS 1000S is best-in-class with full SAASM functionality to meet current and future navigation requirements and is suitable for linefit and retrofit programs. Embedded on many military platforms worldwide, our GNSS suite enables key decision makers to reach the right decisions faster and arrive at sustainable outcomes.

To find out more, scan the QR code or visit [thalesgroup.com](http://thalesgroup.com)

(Mirage 2000 image copyright Dassault Aviation)

# THALES

Together • Safer • Everywhere

## Additional Resources

[1] Dabove P., and M. De Agostino, "What effect does network size have on NRTK positioning?" GNSS Solutions, *Inside GNSS*, November-December 2011

[2] Dach R., and U. Hugentobler, P. Fridez, and M. Meindl, Bernese GPS Software Version 5.0. Astronomical Institute, University of Bern, 2007

[3] Kislig L., "What is a Virtual Reference Station and how does it work?" *Inside GNSS*, July-August 2011

[4] EUREF Permanent Network, "Guidelines for EPN Analysis Centres," document and related mails on-line: <[http://www.epncb.com/be/\\_documentation/guidelines/guidelines\\_analysis\\_centres.pdf](http://www.epncb.com/be/_documentation/guidelines/guidelines_analysis_centres.pdf)>, 2012.

## Authors



**PAOLO DABOVE** is a post-doctoral research assistant at the Politecnico di Torino, Italy. He holds a Ph.D. degree in geomatics engineering from the same university. His major research interests are in quality control of GNSS positioning, kinematic positioning with low-cost GNSS instruments, and network GNSS positioning.


**AMBROGIO M. MANZINO** is a full professor at the Politecnico di Torino, Italy, since 2003. He is member of the Scientific Committee of the SIFET (Italian Society of Photogrammetry and Surveying) and a member of the Scientific Committee of ASITA (Federation of the Scientific Associations for the Territorial and Environmental Information). His major research interests are in



low-cost INS and GNSS systems for mobile mapping applications and in network GNSS positioning.



**CINZIA TAGLIORETTI** is a Ph.D. student at the Politecnico di Torino, Italy, where she also completed her M.Sc. degree in civil engineering. Her major

research interests are in low cost INS and GNSS systems for mobile mapping and navigation purposes and in the network GNSS positioning. 



# PTTI 2013

PRECISE TIME & TIME INTERVAL SYSTEMS & APPLICATIONS MEETING



**TECHNICAL MEETING: DEC 3 – 5, 2013**

**TUTORIALS: DEC 2, 2013**

**SHOW DATES: DEC 3 – 4, 2013**

**HYATT REGENCY, BELLEVUE, WASHINGTON**

## ION PTTI 2013 SESSION TOPICS

Advanced Atomic Frequency Standards Applications | High Performance Time and Frequency Transfer via Fiber | Next Generation PTTI Applications | Network Synchronization and IEEE 1588, NTP | PTTI in Space | PTTI Time and Frequency Laboratory Activities | State of the Art GNSS Timing Receiver Metrology and Applications | Time and Frequency Transfer Applications – Milliseconds to Picoseconds | Time Scales and Algorithms | Panel Discussion | PTTI Vendor Session

**CALL FOR ABSTRACTS DUE: August 2, 2013**

[www.ion.org/ptti](http://www.ion.org/ptti)



# GPS NETWORKING

- **RELIABLE:** Experience Matters
- **ACCURATE:** Trust is built on it
- **AVAILABLE:** Timing and Synchronization
- **CUSTOM:** Built for your needs

## Real World GPS Signal Solutions

GPS Networking has the experience and technical expertise to provide customized GPS Signal Distribution components to solve any GPS application challenge. With over 20 years of experience, our record speaks for itself. We are unsurpassed in the GPS industry for quality and customer service.

800.463.3063 • [www.gpsnetworking.com](http://www.gpsnetworking.com)