Real Time Network Guidelines from NOAA's National Geodetic Survey

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SUMMARY

The National Geodetic Survey (NGS), a program office of the National Oceanic and Atmospheric Administration (NOAA) in the United States of America, has assembled a team of over 60 individuals with the goal of producing guidelines for the rapidly growing infrastructure of real time global navigation satellite system (GNSS) networks in the USA. This team has been divided into four work groups: site considerations, planning and design, administration, and users. A cohesive draft document has been assembled for public review in the fall of 2009. The goal of NGS is to ensure that the users of these real time networks (RTN) can enjoy positional coordinates that are accurate, homogeneous, repeatable, and aligned at an acceptable level to the current realizations of the national datums, i.e., NAD 83 (latitude, longitude and ellipsoid height) and NAVD 88 (orthometric height) as defined and represented in the National Spatial Reference System (NSRS).

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1 BACKGROUND

It is important to understand the level of involvement that can be taken by NOAA's National Geodetic Survey (NGS) with regard to the burgeoning infrastructure of real time networks (RTN) across the conterminous USA. While NGS wishes to support the RTN to ensure alignment to the NSRS, it is prohibited by law against competing in any way with the positioning services offered by the private, academic or scientific sectors. Additionally, NGS cannot accept any remuneration for data supplied – even if only for GNSS observables alone. This model is different than the one employed in some other countries, such as Germany and Great Britain, where the government is the GNSS data supplier from its network of active reference stations, whereby it receives some financial consideration in return. The NGS 10 Year Plan includes accreditation of RTN as National Spatial Reference System (NSRS) compliant (see http://www.ngs.noaa.gov/INFO/NGS10yearplan.pdf). Therefore, the NGS program in support of RTN falls into four main sectors:

1.1 Streaming real time GNSS observables.

These data would be freely available from a selected set of federally owned and/or operated active reference stations and would not contain correctors. The intent here is to have a foundation level network of national continuously operating reference stations (CORS) that can be considered as NSRS fiducial values for all RTN, while not being in competition to GNSS positioning services offered by others.

1.2 Education and outreach to the geospatial positioning community.

With over 200 RTN in the world and with over 80 RTN in the USA (including 35 of the 50 states' Departments of Transportation), NGS realizes the importance of this positioning technology, as well as the potential for mismatched information coming from competing and/or overlapping RTNs. The explosion of the geographic information systems, agricultural and other machine controlled GNSS positioning applications, has brought a wide range of user GNSS sophistication into play. NGS wishes to not only bring an increased knowledge of geodesy and geodetic applications to this community, but to also take in the knowledge available from the world community on RTN principles and practices. Furthermore, the role of NGS, as the provider of the NSRS, is to work with RTN operators to ensure that their customers are receiving coordinates that are compliant with the NSRS. With the replacements for both NAD 83 and NAVD 88 looming within a decade, it is more important than ever to make sure that RTN administrators and users are aware of the proper use of datums in positioning.

1.3 Continuing scientific research.

NGS will continue its work investigating geoid models, satellite orbits, antenna phase center variations, crustal motion, gravimetric datums and other geophysical phenomena in their relation to RTN GNSS positioning. NGS is moving towards GNSS-based orthometric access to the vertical datum with the GRAV-D program (see http://www.ngs.noaa.gov/GRAV-D/). When complete, this datum will supersede the current NAVD 88. Similarly, a massive scientific effort to readjust all CORS data since 1994is underway at NGS, and when complete will pave the way toward more accurate geometric three dimensional positions and velocities, and ultimately will lead to a replacement for the existing NAD 83.

1.4 RTN guidelines.

NGS does not purport to have produced a standard or specification for GNSS RTN positioning with the guidelines. Rather, considering the dynamic nature of the technology and the additional satellite constellations and signals coming on line, it considers their content to be a means of assuring accurate, homogeneous, repeatable coordinates. Other user techniques and RTN configurations may indeed be found to provide equal results. Therefore, rather than the only way to a goal, the guidelines are a confident path to follow to get the user to his desired end.

2 RTN GUIDELINES

NGS welcomes comment on this document from the international geospatial community.
A current draft of these guidelines can be found at the NGS ftp site: ftp://ftp.ngs.noaa.gov/dist/whenning/FIG2010/NGSRTN.doc

Due to the limited nature of this paper, only selected salient points contained in each section are given.

2.1 Site Considerations- Work Group Leader Dan Martin, NGS Geodetic Advisor to Vermont

The existing NGS guidelines for establishing a CORS station (http://www.ngs.noaa.gov/CORS/Articles/CORS_guidelines.pdf) form the basis of the RTN reference station recommendations. However, this Chapter also provides some important general provisions as well as specific recommendations and examples for various types of CORS mounts. Main site considerations include:

2.1.1 Electrical supply.

- Continuous power
- Dedicated circuit, no extention cords

- Voltage regulating equipment

2.1.2 Receiver mounting.

- Accessible for maintenance
- Isolate from moving people and other equipment
- Anticipate and prepare for physical disturbances, such as hurricanes

2.1.3 Security.

- Consider potential risks of tampering or theft.

2.1.4 Building mounts.

- antenna cables greater than 30 m that cannot be located closer to the receiver should use a low impedance cable (e.g., LMR600) or employ an amplifier.
- flush mount provides the best stability (see Figure 1.)
- outrigger and corner mounts can be used for overhang conditions
- use bolts to attach the mount if at all possible

Figure 1. A flush building mount

2.1.5 Ground mounts

- more expensive than building mounts, but more easily located
- A *braced mount*, such as used by Plate Boundary observatory (PBO) are the most stable (see Figure 2)

Figure 2. A deep-drilled braced ground mount

- a *pillar mount* is recommended to be 2 to 2.5 m in height and poured to a depth of 4m. Conduits within the concrete pillar may produce cracks in the pillar over time (see Figure 3).

Figure 3. A pillar mount

- A *tower mount* can be used when obstructions or other considerations require elevating the mount beyond the typical pillar construction heights. The foundation is poured to the same depth as pillar mounts. Guy wires may be needed to stabilize the tower (see Figure 4).

Figure 4. A tower mount

2.2 Planning & Design- Work Group Leaders: Gavin Schrock, Washington State Reference Network Administrator and Matt Wellslager, South Carolina Geodetic Survey

As with any project or business under taking, a thoughtful planning process is essential. A planning phase will inform the design, and operations parameters, as well as govern performance and the ultimate success of the network. Though the goals of the immediate stakeholders govern the planning process, it is in the nature of RTN that they may possibly or eventually serve a broader range of uses than originally envisioned. Designs should not preclude possible future accommodation of additional user segments unless such exclusions are a specific goal of the stakeholders. Planning decision flow could proceed as follows:

2.2.1 Determine the RTN business model and format, including cost/benefit and needs analysis.

2.2.2 Set accuracy and data availability goals. Set fee structure, if any.

2.2.3 Determine service types (i.e., network, single base, static files, etc.)

2.2.4 Evaluate current reference station spacing possibilities. For example, a RTN with 30 km spacing for a 40,000 km^2 area would require approximately 46 stations, where a spacing of 70 km would require only 14 stations. Needs could dictate that urban or high use areas have closer spacing than rural or low use areas.

2.2.5 Evaluate power and Internet availability for the network.

2.2.6 Evaluate station to server and server to user communication integrity and latency.

2.2.7 Design data integrity monitoring and assess the source and method of deriving reference station coordinates. Use of the national CORS system as the source of datum truth.

2.3 Administration – Work Group Leader Gary Thompson, Director, North Carolina Geodetic Survey. RTN Operational Guidelines from Dr. Richard Snay, Chief NGS Spatial Reference System Division.

The administration of the network is the critical element that efficiently operates the various components of the network (e.g. receivers, servers, and communication networks, etc.) to work as a system and distributes the Global Navigation Satellite Systems (GNSS) data and provides the users with the information needed to utilize the network. At a minimum, administratior's should consider the following:

2.3.1 Evaluate hardware infrastructure requirements. Ability to support and maintain computer servers, GNSS equipment and communication links.

2.3.2 Develop response plans to address service outages

2.3.3 Initiate templates for user configurations and a help desk system.

2.3.4 Develop information technology (IT) partnerships for security, firewalls, lightning protection, power back up systems and all communication data flow.

2.3.5 Evaluate data flow bandwidths and latencies.

2.3.6 Establish accurate coordinates on the RTN reference stations that are aligned to the NSRS. (Snay, 2009). The RTN station coordinates must be very precise in the internal RTN adjustment or else any positional error from constrained stations will be moved to the atmospheric modeling in interpolation computations. A RTN aligned within a few centimeters to the national CORS system will enable positions to be validated and monitored by the NGS On Line Positioning User Service (OPUS). Additionally, any points that a user would establish with OPUS can be used with RTN data at high accuracy. NGS recommends a minimum of 3 or 10% (whichever is the larger amount) of each RTN be national CORS. This would enable the use of certain checking and monitoring programs such as a variety of OPUS or TEQC (Translation Editing and Quality Checking program available from University Navstar Consortium –UNAVCO. See http://facility.unavco.org/software/teqc/teqc.html) to produce plots of all RTN reference station ARPs.

2.3.7 Evaluate the means of producing orthometric heights from the RTN. This can result in the use of a high resolution NGS geoid model or from a calibration performed by the user on passive monumentation with trusted orthometric height values. Several methods exist to obtain orthometric heights on the ARP of the RTN station, if this is felt to be an advantage.

2.4 Users – Work Group Leader William Henning, NGS Senior Geodesist.

The goal of the users' guidelines is to provide pertinent information and best methods to enable GNSS RTN positioning with high accuracy at the 95% confidence level. Due to the plethora of variables present in positioning with RTN, and the augmentation of the satellite constellations and signals, these guidelines are expected to be the most dynamic of the four Chapters. The economic advantages of utilizing a RTN service as opposed to employing traditional user-supplied single base RTK have brought many sectors of geospatial applications into its use. Therefore, a common level of methodology will benefit the entire spectrum of users.

2.4.1 Know the three most common types of RTN in the USA. Users should be familiar with the different GNSS manufacturers' RTN solutions- including non-physical (virtual) reference station and master-auxiliary and also with the concept of reverse processing.

2.4.2 The recordation of pertinent metadata is important. Typically, only coordinates and possibly covariance matrices are produced from field RTN locations. It is therefore incumbent upon the user to keep records of campaign information such as: the RTN coordinate basis (datum, adjustment, epoch), any calibrations performed, hardware, firmware and software versions, data collection criteria (number of epochs of data, intervals used, DOP settings, minimum satellites present during collection), conditions such as local weather and space weather, possible multipath conditions, obstructions, etc.

2.4.3 The user should understand the concepts of precision and accuracy in differential GNSS positioning. The user precision is a measure of alignment to the RTN (or to the constrained passive marks as a local projection), while user accuracy is considered by NGS to be the alignment to the national datums. Therefore, NGS encourages all RTN to align to the national datums at certain levels horizontally and vertically using the national CORS network as truth. NGS wishes all RTN to produce positions that are consistent at high accuracy from overlapping or abutting RTN. Additionally, NGS encourages all RTN to provide their data in formats that all users can utilize regardless of their GNSS hardware.

2.4.4 <u>Best methods for GNSS RTN field locations – the "7 C's of NOAA's NGS".</u>

- ***Check*** equipment, data collector parameters and site information. Ensure the rover pole height is accurate. Ensure all projection parameters and project parameters are correct. Test communication to the RTN at the project site.

- ***Conditions***. Use mission planning to ensure the adequate number of satellites and minimum acceptable dilution of precision (DOP) level are present for the campaign. Use consistent weather conditions at the rover and the closest RTN stations in the interpolation cell. Be aware of multipath conditions. Multipath is ill-modeled at best is real time positioning.

- ***Coordinates***. Know what datum, adjustment and epoch is supplied by the RTN and what is needed by the user. Passive monuments are a snapshot in time only accurate to the last recorded visit. Understand that these coordinate values can significantly differ from the active RTN station adjustment.

- ***Communication***. Robust communication is the key to an effective RTN. Latency must not surpass 2 seconds to the user. **NGS promotes the use of Radio Technical Commission for Maritime Services (RTCM) format data messages through the Networked Transport of RTCM via Internet Protocol (NTRIP) communication protocol**. NTRIP is an open, generic, stateless application protocol for streaming GNSS data over the Internet. The software is freely available is available at: http://igs.bkg.bund.de/index_ntrip.htm. Wireless internet availability via cell technology should be researched for the user's area. For areas without cell coverage, work can proceed with a user base station using UHF, VHF or spread spectrum radio communication. In areas without control coordinates, an autonomous position can be used to produce differential vectors on the points of interest. Subsequently, the refined base station coordinate can be entered into the field or office software thus shifting the vectors to produce accurate positions. The autonomous base position can be refined to high accuracy using the NGS program OPUS with as little as two 15 minute occupations (OPUS-RS) or one 2 hour session (OPUS-S). See http://www.ngs.noaa.gov/OPUS/ for further information. <u>If the RTN is compliant to the NGS guidelines and thus aligned to the NSRS, positions produced using these methods will be homogeneous to work done from RTN produced coordinates throughout the RTN coverage area</u>.

- ***Constraints to Local Monumentation***. Well planned and administered RTN have shown high precision in the horizontal coordinate data positioned from them. However, currently, for the best <u>orthometric height</u> precision from a RTN, a calibration to at least four trusted benchmark monuments should be performed in addition to configuring the rovers to use the <u>current NGS hybrid geoid model</u> (Geoid 09 at this writing). These benchmarks should form a rectangle on the outside of the project area to the best extent possible. Additional monuments with trusted orthometric heights are beneficial- especially if these can be distributed throughout the project area (See Figure 5**)**. Calibrations have the additional benefit of giving the user a picture of how the existing vertical control monuments fit together and which monuments may be outliers. Care should be exercised when constraining certain monuments or removing them from the constraints. Remember that an apparent outlier can in actuality be the monument closer to the project "truth" than the other ones that are homogenous. If this recommended method is not possible, a sub-optimal approach can be taken for heights if there are only two trusted bench marks at the project site. Users report success with a two point vertical calibration, with one point used to move the hybrid geoid model up or down to align to a local vertical datum and the second point used as a check. This then reduces the orthometric "truth" to one monument, so it must be a trusted, verified mark of high integrity to have reasonable confidence in the resulting data constraining this passive monument.

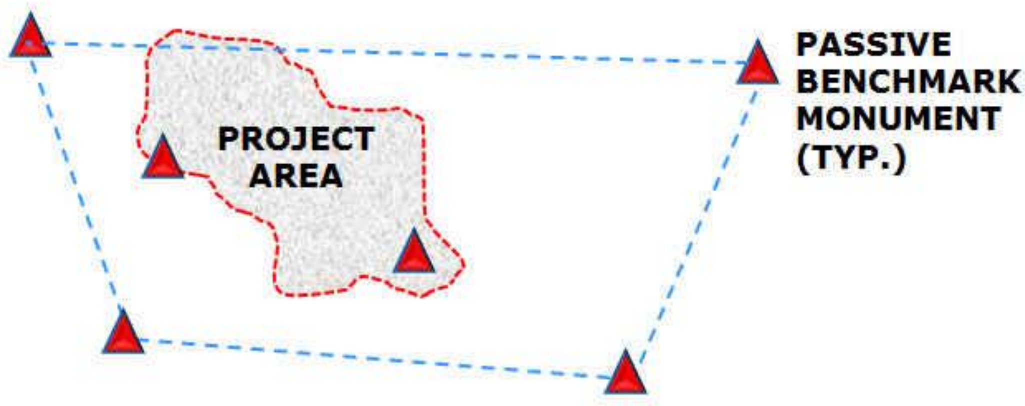

Figure 5. Example of working within a calibration rectangle (quadrilateral, in this case)

- ***Collection***. Check a known point before, during and at the end of data collection. This should provide a method of detecting rover configuration blunders, such as incorrect antenna heights, incorrect projection parameters or faulty calibrations. It also provides a check on the initialization or ambiguity resolution. Periodic checks on known points should also be done as work progresses- perhaps every 3 hours to utilize different satellite geometry and certainly if communication to the RTN or initialization is lost and reacquired. Set an elevation cut-off angle (mask) of between 10° and 15°. For **important, high accuracy** points, the NGS RTN guidelines currently recommend:

GDOP ≤ 3 (or PDOP ≤ 2.5)
Cut off angle of 10°
Number of GPS satellites ≥7
Time on point = 5 second record intervals for 1 minute
Position RMS ≤ 0.02 m horizontal, 0.04 m vertical.
Redundancy ≥ 2 locations staggered by 4 hours. Redundant locations must differ no more than the desired point accuracy from the average of the coordinates as located.

- ***Confidence***. With the plethora of variables associated with RT positioning, collecting accurate, repeatable data depends on three main things: redundancy, good wireless communication links, and checking known points. <u>Redundancy</u> is the king of RTN GNSS positioning. Two or more locations on important points give validity, show repeatability with different satellite configurations and field conditions, and enable position refinement within the software. <u>Robust wireless Internet connectivity</u> ensures low latency data are transmitted to the rover and taht the link is continuous during data collection. <u>Checks on known points</u> before, during and at the end of the data collection session show the precisions with which the whole system is still working and that no blunders such as an incorrect antenna height or incorrect ambiguity resolutions have occurred.

3 INTERACTION WITH FIG COMMISSION 5

NGS hopes to continue its work with FIG Commission 5 in many areas. One task taken on is to work with the Commission work group 5.1 - in charge of standards, quality assurance and calibration, to compile international RTN guidelines available through the various national agencies as well as to post pertinent information on real time positioning and developing GNSS applications. To further this end, NGS, in collaboration with work group 5.1, has started work on a web page to provide access to existing public sector RTN guidelines- either with publication of the actual documents or through links to the appropriate sites. A report on this web page will be forthcoming for the next FIG conference. Work group chair David Martin (martin@esrf.fr) and NGS liaison William Henning (william.henning@noaa.gov) welcome participation and contribution from the international geospatial community. Subsequent work will be to produce a comprehensive set of RTN guidelines emphasizing best methods for accurate GNSS positioning. Without an international standard, RTN best practices developed by small groups (either for academic or marketing purposes) will not achieve the greater goal of absolute accuracy of RTN within a national or international datum, nor will it address the issues which will plague overlapping RTNs which process data in different ways. There exist many pertinent public sector documents on real time positioning from around the globe that could be of great benefit to RTN users and administrators when compiled into the web site. Some few examples representative of available guidelines and excellent geodetic information would include:

-AUSPOS, Australia http://www.ga.gov.au/geodesy/

-Edwards S., Clarke P., Goebell S., Penna N., 2008, "An Examination of Commercial Network RTK GPS Services in Great Britain", Report from Newcastle University to The Survey Association of the United Kingdom, web page:http://www.tsa-uk.org.uk/guidance.php

-EUPOS, Europe http://www.eupos.org/

-Henning, W., NGS, 2008, *NGS User Guidelines for Single Base Real Time Positioning,* National Geodetic Survey. Web link: http://www.ngs.noaa.gov/PUBS_LIB/NGSRealTimeUserGuidelines.v3.1.1.pdf

-Institute of Navigation http://www.ion.org/publications/

-Jaakko Santala and Seppo Tötterström, 2002, The Status of Virtual Reference Systems (VRS)On Testing RTK-Network Virtual Concept, FIG XXII International Congress Washington, D.C. USA, April 19-26 2002

-Norin D., Hedling G., Johansson D., Persson S., Lilje M., *Practical Evaluation of RTCM Network RTK Messages in the SWEPOS™ Network,* Presented at ION ITM 2009 (Institute of Navigation International Technical Meeting 2009), January 26-28 2009, Anaheim, California, USA. Copy available at: ftp://ftp.ngs.noaa.gov/dist/whenning/FIG2010/

-Rizos, C., (1999), Principles and Practice of GPS Surveying, accessed via the web, July 2008, Chapters 3,6,10:http://www.gmat.unsw.edu.au/snap/gps/gps_survey/principles_gps.htm

-University of Calgary http://www.geomatics.ucalgary.ca/graduatetheses

-SAPOS, Germany http://www.sapos.de/

-University of New South Wales http://www.gmat.unsw.edu.au/

BIOGRAPHICAL NOTES

Mr. Henning is a Registered Professional Land Surveyor with over 41 years of active experience in all phases of surveying technology. He has helped plan, construct, process, adjust and manage municipal geodetic networks in the United States. He has been actively involved with education/outreach to the geospatial community for almost 20 years, presenting over 70 talks and workshops on surveying and GNSS technology. Mr. Henning is an ACSM/AAGS Fellow and Past President of the American Association for Geodetic Surveying (AAGS) . He is currently employed by NOAA's National Geodetic Survey (NGS) as a Senior Geodesist, where he is helping to develop guidelines and support methodology for real time positioning with state, national and international organizations.

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