Swedish User Guidelines for Network RTK

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Summary

RTK is an effective technique for accurate positioning in real time with GNSS. The development of the network RTK services based on permanent GNSS reference stations, e.g. SWEPOS^{TM} in Sweden, has made it possible for basically anyone to use the technique. However, serious errors can be introduced into the positioning if the user has no, or only modest, knowledge of the factors affecting the network RTK observations. Hence, the need of user guidelines for this technique is essential.

This paper presents short and easy-to-use guidelines for network RTK users. The guidelines are based on experiences, theoretical studies and recommendations from several other countries. The guidelines consist of information or recommendations regarding the equipment, the equipment settings and software, planning and preparation, quality indicators, field procedures, control procedures, and finally the possible achievable accuracy levels.

Some examples from the guidelines can be summarized as follows: the minimum number of available satellites recommended is 5-7 (minimum 6 if both the GPS and GLONASS system are used), depending on the precision requirements. PDOP recommendations are set to maximum 3-4, and even down to 2 if high precision is crucial. An elevation mask recommendation is set to 13-15 degrees to minimize multipath and atmospheric disturbances. A time separation of 20-45 minutes (or preferably more) for control or re-measurement of a point is recommended to reduce the time correlation effects which influence the observations. Time correlation effects occur due to multipath effects and the atmosphere, in combination with slowly changing satellite constellation.

1. Introduction

GNSS (Global Navigation Satellite Systems) is nowadays a frequently used positioning method and by the RTK (Real Time Kinematic) technique it is possible to achieve centimetre level positioning in real time. Network RTK services based on permanent GNSS reference stations, e.g. SWEPOS^{TM} in Sweden, has made it possible for basically anyone to use the technique. Serious errors can be introduced into the positioning if the user has no, or only modest, knowledge of the factors affecting the network RTK observations. Some of the factors are the satellite constellation, the different equipment settings, environmental and atmospheric effects, correlations in time, etc., and the need of user guidelines for this technique is essential. For that reason this paper presents the results from a project where the objective was to develop short and easy-to-use guidelines for network RTK users. The user guidelines are based on an extensive material of experiences, theoretical studies and recommendations from several other countries. The guidelines consist of information or recommendations regarding the equipment, the equipment settings and software, planning and preparation, quality indicators, field procedures, control procedures, and the possible achievable accuracy levels. Guidelines for the RTK/network RTK technique already exist in more extensive formats (e.g. Henning 2008, Norin et al. 2006). However, this paper attempts to summarize experiences, studies and guidelines into a short format version, with the addition of some proposed control methods and expected accuracy levels. In this paper it is assumed that the reader has a basic knowledge of GNSS and RTK theory.

In section 2 the content of the user guidelines is outlined, in section 3 the user guidelines are briefly listed and summarized and finally in section 4 a future development of the guidelines is discussed.

2. User guidelines for Network RTK

In this chapter some of the content of the guidelines is presented. The chapter is divided into five different sections. In section 2.1 the GNSS receiver and antenna are discussed, followed by recommended preparations in section 2.2. Section 2.3 presents settings and quality indicator information and section 2.4 deals with other recommended parameters to consider. Finally in section 2.5 the recommended surveying and control procedures are outlined.

2.1 GNSS receiver

Old firmware in the GNSS receiver which is not compatible with recent RTCM format is not recommended, since a high quality of the measurements can not be guaranteed. Old firmware do not fulfil today's requirements of the algorithms and corrections for positional accuracy, float and fixed ambiguities, etc. It is recommended to update the firmware according to the specification from the network RTK service provider and the manufacturer's instructions (Norin et. al 2006).

An appropriate choice of antenna and antenna model is required to assure the highest possible precision of the measurements. The antenna phase center (APC) is the point to where the GNSS signal is measured. The antenna model describes the variations of the antenna phase center (PCVs) relative to the antenna reference point (ARP).

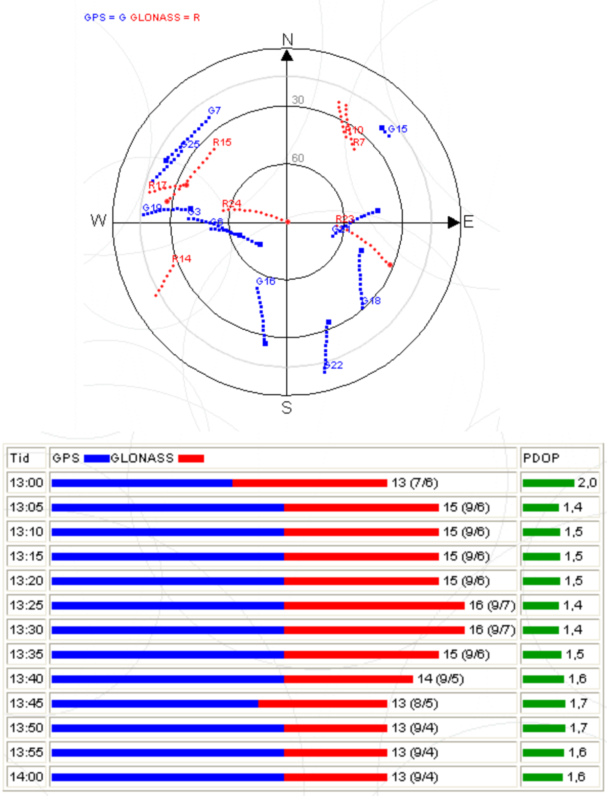
Traditionally, NGS (National Geodetic Survey) models the phase center based on a relative variation from an antenna (AOAD/M_T) used as a reference. This is called a relative antenna model (Henning 2008). The Swedish Network RTK service is today based on these relative models, which leads to the recommendations for the user to use the NGS relative antenna models as well.

In addition, the type of antenna is important for accurate positioning. Different antennas are more or less sensitive to various disturbances, e.g. one type of antenna might be more appropriate receiving low elevation signals from satellites, but worse at mitigating multipath errors. In general, newer types of antennas mitigate multipath effects better than old ones (Henning 2008).

The recommendation for users requesting higher availability of satellites is to invest in equipment and firmware capable of receiving signals from multiple satellite systems, e.g. GPS and GLONASS, and in the near future integrated with the European satellite system Galileo. More satellites normally assure a safer and faster determination of the ambiguity fixed solution and increase the satellite availability where obstacles are present (Henning 2008).

2.2 Preparation

Satellite prediction for surveying in obstructed areas might increase the satellite availability and make it easier to achieve fixed ambiguities, if an appropriate time-slot is selected, see skyplot in figure 1 from www.swepos.com.



Tid	GPS 🟦 GLONASS 🟥	PDOP
13:00	13 (7/6)	2,0
13:05	15 (9/6)	1,4
13:10	15 (9/6)	1,5
13:15	15 (9/6)	1,5
13:20	15 (9/6)	1,5
13:25	16 (9/7)	1,4
13:30	16 (9/7)	1,4
13:35	15 (9/6)	1,5
13:40	14 (9/5)	1,6
13:45	13 (8/5)	1,7
13:50	13 (9/4)	1,7
13:55	13 (9/4)	1,6
14:00	13 (9/4)	1,6

Fig. 1. *Skyplot, with elevation cut off angle of 15degrees, table of number of satellites available and PDOP.*

The minimum number of available satellites recommended is 5-7 (minimum 6 if both the GPS and GLONASS system are used), depending on the precision requirements. Minimum 5 satellites for normal detail surveying and minimum 7 for e.g. determination of a “fixed” point. Prediction tools are also useful to investigate the satellite geometry at a specific time (Positional Dilution of Precision, PDOP), and not only to investigate the number of satellites that will be available. Additionally, in some office software it is possible to set an elevation mask and draw obstacles, consequently receiving an estimation of the quality indicators for the specific time epoch (Norin et. al 2006). Moreover control, and if necessary, calibration of the optical plumb of the antenna pole are also important preparations.

2.3 Settings and quality indicators in the GNSS receiver

The settings in the GNSS receiver are essential to achieve an acceptable quality of the GNSS measurements. The different instrument-reported quality indicators are useful for real time or post evaluation of the measurements.

The elevation cut off angle prevents the signals from low elevation satellites to be used in processing in the receiver. Lower elevation of the satellites consequently yields a longer path for the signal to be transmitted through the atmosphere (which disturbs the signal) and increases multipath influences. The recommendation is to set the elevation cut off angle to 13-15 degrees, however it is then necessary to make sure that the satellite geometry is satisfying e.g. low PDOP (Emardson et al. 2009, Edwards et al. 2008). According to Emardson et al. 2009, a full constellation of GPS, GLONASS, Galileo and COMPASS satellites will in the future probably change this recommendation for the elevation cut off angle to 24 degrees.

DOP (Dilution of Precision) is a measure of the geometry of the satellites relative to the receiver. PDOP is in three dimensions and is recommended to maximum 3-4. PDOP of maximum 2 is recommended for even higher precision requirements (Norin et al. 2006). A good geometrical dispersion of the satellites yields a lower PDOP.

The instrument-reported coordinate quality measures are given by most manufacturers’ as 1σ. The user should multiply this number by two (2σ) to be at least 95% confident that the measurements are within this level. However, multipath effects for a short period of time (seconds to minutes) are not included and modelled into these instrument-reported values, which can give the user a misleading impression of expected accuracy (Edwards et al. 2008, Henning 2008).

The user should make sure the best geoid model is downloaded into the receiver to be able to determine accurate orthometric heights. In Sweden the geoid model SWEN08_RH2000 has an accuracy (1σ, standard error) of 10-15 mm in the entire country, except in the mountainous areas (Ågren 2009). Additionally, it is important to use proper coordinate transformation parameters. If a local system is preferred instead of a national/global reference frame, it is generally necessary to correct for residuals generated by the transformation by a rubber sheeting model.

2.4 Other parameters to consider while surveying

There are several other parameters to consider while using the network RTK-technique. In section 2.4.1 atmosphere errors and multipath errors will be discussed. In section 2.4.2 some error indicators will be described, for instance float and fixed ambiguities, radio and GPRS/GSM communication, SNR (Signal to Noise Ratio), latency and RTK-age.

2.4.1 Atmosphere and multipath errors

The troposphere is the lower part of the atmosphere (approximately 0-10 km) consisting of a wet and dry part, where the wet one is the most problematic part of the troposphere to model. If the reference stations are far away from the receiver or have a large height difference in comparison with the receiver, the errors from the troposphere increase significantly (especially in the vertical component). To decrease troposphere errors the user should, if possible, survey when the weather is similar, or close to similar, at the reference stations and at the location of the receiver (Henning 2008).

The ionosphere is the upper part of the atmosphere and the impact on the ionosphere comes primarily from solar activity, contributing to the number of free electrons in the ionosphere, which disturbs the network RTK measurements. These disturbances involve radio communication loss, initialization problems, loss of tracking of GNSS satellites, low precision of the measurements, etc., and they might occur more or less in different locations and at different times of the day and year.

The number of solar cycle sunspots affects the total amount of electrons in the ionosphere and according to predictions made by NOAA Space Weather Prediction Center the next solar cycle sunspot maximum will occur in the end of 2013 (figure 2).

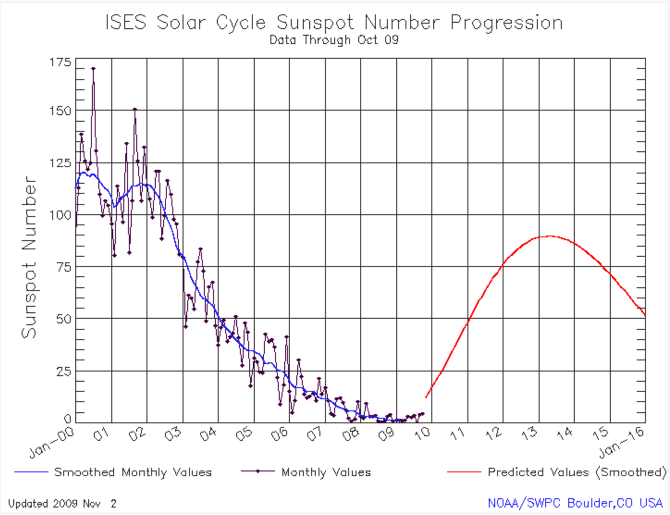


Fig. 2. *Solar cycle sunspot maximum will occur in the end of year 2013 according to the predictions made by NOAA http://www.swpc.noaa.gov/SWN/index.html).*

Figure 3 shows an ionospheric scintillation map and illustrates the parts of the world that will be mostly affected by a solar maximum, where the equator will be affected up to 100 days per year, pole-ward latitudes will be affected less, and finally the mid-latitudes will be affected a few to ten days per year. Scintillation is a kind of space-based multipath effect, where a planar radio wave strikes a volume of irregularities in the ionosphere, and then emerges as a surface of nearly constant amplitude but variable phase (Kintner et al. 2009).

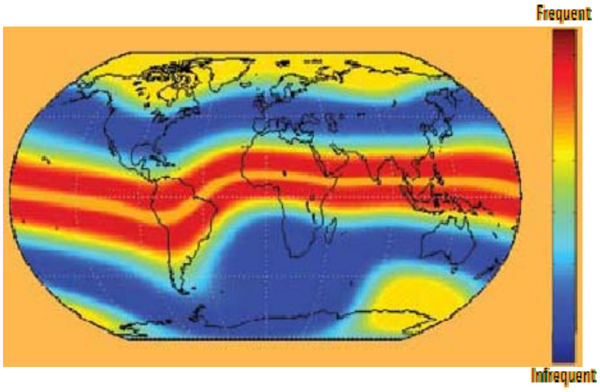


Fig. 3. *Ionospheric scintillation map which shows the effects of a solar maximum in different parts of the world (Kintner et al. 2009).*

Reports of geomagnetic storms, solar radiation storms and radio blackouts can be found and described at http://www.swpc.noaa.gov/SWN/index.html. Geomagnetic storms of scale G3-G5, solar radiation storms of scale S4-S5 and radio blackouts of scale R3-R5 are levels where the user should be cautious and preferably not use the RTK technique (Henning 2008).

In addition SWEPOS (network RTK service provider in Sweden) will hopefully in the future present real time measurements of the solar activities at www.swepos.com, informing and warning the users of possible problems of high ionosphere activity.

A recommendation to discover tendencies of possible problems with the ionosphere is to control a well-known fixed point located close to the office and pay close attention to the accuracy, especially in the vertical component.

Multipath errors over a short period of time (seconds to minutes) are difficult, or even impossible, to model and the serious problem with these multipath errors is that the receiver does not reveal them in the instrument-reported coordinate quality measures. Redundant measurements with different satellite constellations are a possible way to mitigate multipath errors.

Figure 4 is taken from an evaluation study of the Great Britain network RTK service, by Edwards et al. 2008, where Trimble and Leica were network RTK correction providers (and equipment manufacturers). The results are shown in pink and purple colour, not revealing which one is Leica or Trimble. The figure shows measurements of a point in an environment with multipath effects, where the vertical axis shows the ratio of the obtained RMS-value (compared to a “known” point) divided by the instrument-reported coordinate precision indicators. In a best possible case the ratio should obviously be equal to 1, but the "pink" equipment (light grey in a black and white print-out) shows an overoptimistic instrument-reported precision of a factor 3-5.

2.4.2 Error indicators

A fixed ambiguity is reached when the receiver has locked the carrier phase and calculated the integer value of the whole cycle counts from the receiver to each satellite for each frequency. This integer value is then added to the partial cycle which the receiver record and the surveyor can start measuring at a centimetre level (called fixed solution). Float solution is when the receiver still has not been able to fix the whole cycle counts to an integer (decimal count) and the precision is obtainable at meter to sub-meter level. A correctly calculated fixed ambiguity resolution is according to most of the manufacturers possible to obtain with a confidence of 99.9% (Henning 2008). According to some recent studies it takes approximately 10-40 seconds (in 68 % of the cases) to obtain a fixed solution today (Johansson & Persson 2008, Johnsson & Wallerström 2007).

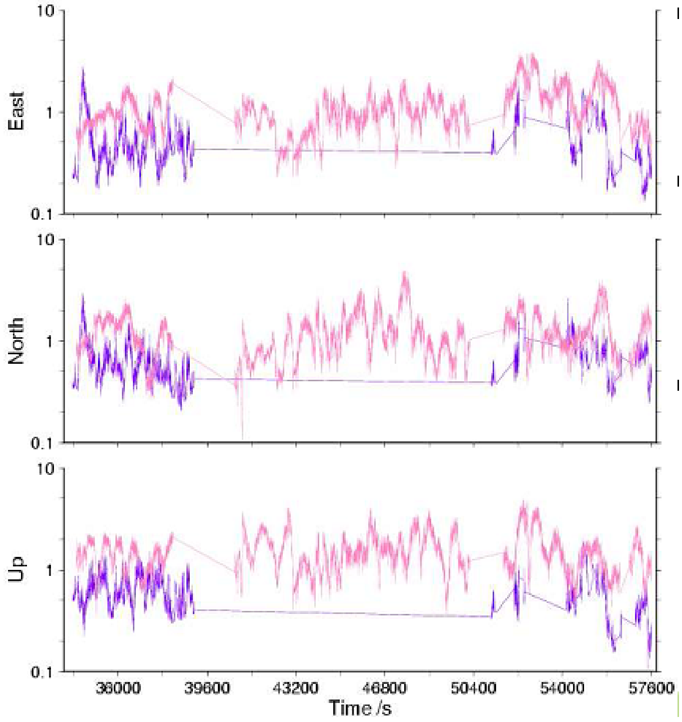


Fig. 4. *The "pink" equipment (light grey in a black and white print-out) shows an overoptimistic instrument-reported precision of a factor 3-5 in a multipath-affected area (Edwards et al. 2008).*

On an everyday basis the surveyor should regularly control the obtained fixed solution by re-measuring a point originally measured with another fixed solution, or control a "known" fixed point, to minimize the probability of an incorrect fixed solution. Some receivers have an automatic function to control the fixed solution. This function calculates another fixed solution and compares it with the initial one. However, the recommendation to manually control the fixed solution still remains (Henning 2008).

Discontinuities of the communication link for the radio or GPRS/GSM should always be avoided as it might yield low precision measurements. The user should pay close attention to the quality of the communication and one indicator for this is "quality of radio link", which normally is shown in percent. Additionally, the user should avoid using electronic equipment (e.g. mobile phones) nearby, which might disturb the communication (Henning 2008).

One indicator in the receiver for discovering possible multipath errors is the SNR (Signal to Noise Ratio), which additionally indicates if there is a problem with atmospheric disturbances. However, no standard presentation or standard algorithm is available for this indicator, and the user is recommended to read the manufacturer's manual to obtain the presentation and the warning level (Henning 2008).

Some users might not be aware of the fact that the coordinates are displayed with latency. In worst-case scenarios the latency can be up to 5 seconds, which can lead to unacceptable coordinates.

Another important indicator to pay close attention to is the RTK-age, which should be around zero or one second. Corrections older than a few seconds might be erroneous corrections sent to the receiver (Henning 2008).

2.5 Surveying and control procedures

The centering error is important to consider if the measurements are required to have a high precision (horizontally), and a tripod (or supporting legs) for the antenna pole is needed to minimize this error. The centering standard error (1σ) has been estimated to 14 mm for an antenna pole of two meters in height and without a tripod (Odolinski & Sunna 2009).

Redundant measurements (averaging) are important to minimize noise in the GNSS observations and to find gross errors. In addition redundancy increases the user's confidence of the measurements. The recommended minimum number of observations to average is 3-30, depending on the precision requirements (Norin et al. 2006).

Control of a well-determined "check point" (e.g. determined with GNSS) near the office might help the user on an everyday basis (before and after surveying) to guarantee that all receiver settings are correct, assure that no atmospheric disturbances will have an effect on the measurements, etc. An accepted deviation ($\leq$ expected accuracy level) when controlling a check point might be ± 30 mm in the horizontal and ± 50 mm in the vertical component (at least 95 % confidence level and with no error assumed in the check point). The expected accuracy levels were calculated using the error propagation law and estimated standard errors from earlier studies in Sweden (with the assumption of no correlations in the measurements and a tripod (or supporting legs) used for the antenna pole):

$$\Delta^{check\ point}_{horizontal} = 2\sqrt{\sigma^2_{horizontal}} \approx 30\,mm$$

$$\Delta^{check\ point}_{vertical} = 2\sqrt{\sigma^2_{height}} \approx 50\,mm$$

where,

2 = used to obtain expected accuracy level at a 95% confidence level (at least),

$\sigma_{horizontal}$ = 15 mm, horizontal std. error (Johnsson & Wallerström 2008),

σ_{height} = 27 mm, std. error in height, no geoid error included (Emardsson et al. 2009)

Note that the geoid standard error is eliminated when measuring a point originally measured with GNSS, due to the fact that the two measurements have the same geoid error (assuming that the same geoid model was used). Additionally, the height standard error from Emardson et. al 2009, was estimated with a satellite constellation of GPS + GLONASS and in a network with a distance of 70 km between each reference station.

Control of “known” points or revisits of points during field work can be used to check all points measured with a certain fixed solution or to check the recently obtained fixed solution. In the calculation of the following expected accuracy levels it is assumed that no tripod (or supporting legs) is used during field work.

An accepted deviation (≤ expected accuracy level) for a control of a known point might be ± 40 mm in the horizontal and ± 60 mm in the vertical component (at least 95 % confidence level and no error in the known point). These levels were calculated analogously to the previous levels, except of the addition of a centering standard error in the horizontal component (it is assumed that the centering error does not affect the height component) and a geoid standard error (from the network RTK measurement) in the vertical component:

$$\Delta^{known\ point}_{horizontal} = 2\sqrt{\sigma^2_{horizontal} + \sigma^2_{cent.}} \approx 40\,mm$$

$$\Delta^{known\ point}_{vertical} = 2\sqrt{\sigma^2_{(height+geoid)}} \approx 60\,mm$$

$$\sigma_{(height+geoid)} = \sqrt{\sigma^2_{height} + \sigma^2_{geoid.}}$$

where,

$\sigma_{cent.}$ = 14 mm, centering std. error (Odolinski & Sunna 2009)

σ_{geoid} = 15 mm, geoid std. error (Ågren 2009)

Before revisiting a point originally measured with network RTK it is important to reinitialize to obtain an independent calculated fixed solution. When revisiting a point the user also has to consider the time correlations which affect the measurements. Time correlation effects occur due to multipath effects and the atmosphere, in combination with slowly changing satellite constellation.. Time separation of 20-45 minutes for controlling or re-measuring a point is recommended to reduce the time correlation effects and to assure a more confident estimation of the accuracy obtainable. Note that even 5-10 minutes of time separation decreases at least some of the time correlation effects (Odolinski 2011).

An accepted deviation (≤ expected accuracy level) for a revisit of a point originally measured with network RTK might be ± 60 mm in the horizontal and ± 80 mm in the vertical component (at least 95 % confidence level). The expected accuracy levels were calculated using the error propagation law and the same standard errors and assumptions as before (note that the geoid standard error is eliminated when revisiting a point originally measured with network RTK):

$$\Delta^{revisit}_{horizontal} = 2\sqrt{2\sigma^2_{horizontal} + 2\sigma^2_{cent.}} \approx 60\,mm$$

$$\Delta^{revisit}_{vertical} = 2\sqrt{2\sigma^2_{height}} \approx 80\,mm$$

If all these expected accuracy levels are exceeded there might be gross errors and the measurements should be further investigated.

According to a study of the network RTK service in Great Britain a horizontal standard error was estimated to 10-20 mm and the standard error in height to 15-30 mm (1σ, geoid standard error excluded) (Edwards et al. 2008). The study used a tripod for the antenna and the measurements were carried out during normal environmental conditions and during regular solar activity conditions. The study confirms the standard errors used in this paper in the calculation of the different expected accuracy levels. The upcoming solar cycle sunspot maximum in the year of 2013 will probably worsen the accuracy, in particular in the vertical component.

3. Summary

The user guidelines can be briefly summarized as follows:

GNSS receiver

- It is recommended to update the firmware according to the specification from the network RTK service provider and the manufacturer’s instructions
- Choose appropriate type of antenna (and antenna PCV model)
- Use a GNSS receiver capable of receiving GPS and GLONASS corrections when surveying in areas with many obstacles

Preparation

- Control, and calibrate the optical plumb of the antenna pole if necessary
- Use satellite prediction tools if high satellite availability and good satellite configuration is necessary

Settings and quality indicators in the GNSS receiver

- The elevation cut off angle is recommended to 13-15 degrees for today's satellite constellation
- PDOP recommendations are set to maximum 3-4 depending on the precision requirements (even a maximum of 2 if high precision is necessary)
- The instrument-reported coordinate quality measures should, for the most manufacturers, be multiplied by two (2σ) to be at least 95% confident that the measurements are within the desired accuracy level. Note that multipath effects for a short period of time (seconds to minutes) are not included and modelled into these instrument-reported values

Other parameters to consider while surveying

- The GSM/GPRS communication should be continuous, a possible indicator in the receiver is quality of radio link
- Pay attention to the SNR (Signal to Noise Ratio) for an indication of possible multipath errors, atmospheric disturbances, radio frequency collisions, etc. Read the manufacturer's manual for the presentation and the warning level
- Pay attention to if RTK-age (age of the correction data) exceeds several seconds as that might influence the precision of the measurements

Surveying and control procedures

- Minimum averaging recommendation is set to 3 measurements (preferably 3-30) to mitigate GNSS noise and to find gross errors
- Use a ”check point” close to the office on a regular basis (before and after surveying) to control the settings in the receiver, to investigate if atmospheric disturbances affected the network RTK measurements, etc. An accepted deviation from a check point might be ± 30 mm horizontally and ± 50 mm vertically (95 % confidence level, tripod used and no error assumed in the check point)
- Control the fixed solution and the network RTK measurements on a regular basis by measuring a “known” point, or by revisiting a point originally measured with network RTK technique
- An accepted deviation from a known point might be up to ± 40 mm horizontally and ± 60 mm vertically (95 % confidence level, no tripod used and no error assumed in the known point)
- An accepted deviation for a revisit might be up to ± 60 mm horizontally and ± 80 mm vertically (95 % confidence level and no tripod used). When revisiting it is important to use a time separation of at least 5-10 minutes, even though 20-45 minutes or more are preferred to reduce time correlation effects (e.g. by receiving a different satellite constellation) and to assure a more confident estimation of the accuracy obtainable

4. Future

The recommendations will probably improve over the years, and it is of great importance to keep the guidelines updated. The accuracy levels will most likely improve with additional satellite constellations, e.g. Galileo. According to Emardson et al. 2009, the elevation cut off angle recommendation might change from 13-15 to 24 degrees for a full constellation of GPS, GLONASS, Galileo and COMPASS satellites. Additionally, more information about possible real time measurements of solar activity (e.g. by SWEPOS) might be inserted into the guidelines, etc. In the future guidelines for GNSS integrated with a totalstation (e.g. Leica Smartstation or Trimble IS Rover), or possible integrated with INS (Inertial Navigation Systems), will be an important issue to consider.

These network RTK user guidelines are published in a report called “User Guidelines for Network RTK” at the Geodetic Research Department of Lantmäteriet (Swedish mapping, cadastre and registry authority) (Odolinski 2010) (In Swedish).

Acknowledgement

The author wants to thank his former colleague Johan Sunna at Lantmäteriet for editing this paper into the NKG-format.

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