Guidelines for the Network RTK (NRTK) Survey

The use of RTK (Real Time Kinematics) in GNSS reference station networks has become the general tool and quickly spreading solution for high precision positioning using Global Navigation Satellite Systems (GNSS). The RTK network approach is the evolution of single base RTK positioning technique, to achieve consistent accuracy and increased range in comparison to single base RTK.

Both RTK and RTN GNSS surveys can achieve relative positioning with centimetre (cm) precision when following a set of best practices. There are several important factors that need to be accounted for when doing RTK/RTN surveys. Many of these are common to other types of GNSS surveys and include: equipment calibration, atmospheric errors, multipath, satellite geometry, reference system integration, redundancy, and validation. There are also some recommendations in this document which are unique to RTK/RTN surveying such as rover setup, communication problems, time windowing, and initialization.

The goal of this document is to provide a set of concise and easy to follow best practice guidelines that the surveyor should be familiar with and keep in mind when performing RTK Survey. Additional recommended references and web links have also been included for users. Due to the rapidly changing environment of Global Navigation Satellite System (GNSS) positioning, it is understood that this document will be dynamic, improvements to GNSS hardware and software, increased wireless communication capabilities, new signals, and additional satellite constellations will yield significantly easier, faster and more accurate RT positioning in the near future, which will require periodic updation of this document.

Architecture of RTK Network

The concept of permanent GNSS reference stations networks started to expand early in year 1990.The idea is based on establishment of several GNSS reference stations at points with known coordinate connected to a central server managing the whole network. The central server receives at time interval via mean of communications, the GNSS raw readings for each GNSS station and its correction, and then the server can model the error in the area, and produces the required corrections for GNSS rovers within the coverage area.

The RTK network of permanent GNSS reference stations is an evolution of the DGPS concept, where the correction of the GNSS reading at fixed GNSS station is applied at rover position to increase the accuracy of rover positioning. The RTK network establishes several GNSS reference stations that transmit their observed data to a control server in real time and control server manages the whole system, and then transmits the corrections to users within coverage area.

RTCM Correction Data for GNSS Positioning

The correction data for GNSS-Positioning within RTK networks is a challenging process, and is depending on the architecture of the RTK networks especially the communication tier between rover and control server. Mainly, there are three main methodologies for correcting data in RTK networks for GNSS-Positioning using the RTCM standard, first the Virtual Reference Station (VRS) technique, which requires duplex communication between rover and control server. Secondly, the Area-Correction Parameters (ACP) technique commonly known as FKP can work in simplex mode (broadcasting corrections) or duplex mode. Finally, the Master Auxiliary Concept (MAC) based on simplex mode. AutoMax and iMax are duplex variants of MAC method. For UP and UK CORS network **Virtual Reference Station (VRS) technique**, is recommended to achieve fast and accurate results.

General Guidelines

1. **Equipment for RTK Survey**
    a. Any Industry standard GNSS equipment of any make/model can be used for RTK survey, however GNSS equipment need to be enabled for RTK correction and paired with Controller and specific Survey software (i.e. Trimble Access or Leica Captivate), required to carryout RTK settings as well as visualizing and storing RTK position and Qualitative indicators of Survey. Foe ease of understanding set of both of these equipments will be termed as RTK Rover in further reading of these guidelines.

    b. RTK Rover also required access to internet if being used to access Correction from CORS Network. Access to internet can be made via inbuilt phone modem in GNSS equipment or its controller, or can be provided by an external phone modem via wifi, Bluetooth or USB port.

    c. Using GPS+GLONASS rather than GPS-only can lead to small improvements of a few millimetres in both horizontal and vertical positional accuracy. The use of Multi-frequency and multi-constellation GNSS is recommended for use of RTK survey.

    d. For Control work purpose only Geodetic grade Multi-frequency and multi-constellation GNSS RTK rover are to be used.

    e. For GIS applications RTK rover mount over a Survey Pole with or without bipod support can be used, however for Control work purpose RTK rover are to be used with Stable mounts i.e. Pole with bipod or tripod-tribrach-adopter assembly.

    f. For Control work purpose RTK rover, are to be used with Stable mounts i.e. Pole with bipod or tripod-tribrach-adopter assembly.

    g. Batteries of Controller as well as Rover Instrument should be fully charge before commencing observation.

    h. If RTK rover has Multi-frequency and multi-constellation features, ensure that the Rover is configured for multi constellation and multi frequency logging.

    i. Please ensure your Network RTK rover firmware is configured according to manufacturer guidelines. Even a minor variation from recommended settings may lead to unacceptable variations in determined coordinates or no solution at all.

    j. The measured GNSS position is always determined relative to the APC. However, the surveyor in the field is normally interested in the coordinates of a point on the ground. Several important factors are to be accounted for to translate the APC position to the monument (or ground) position. Use an absolutely calibrated antenna type and apply the calibration model. In most cases this requires entering the correct antenna type into the rover and the receiver software will take care of applying the model. Information and absolute calibration models can be found at http://www.ngs.noaa.gov/ANTCAL/.

i. It is also important to record the Antenna Reference Point (ARP) used, and the antenna type manually.
ii. Centering on the point must be done very precisely.
iii. The instrument must be leveled properly since a small error in the horizontal plane determination can cause antenna phase centering error with larger repercussion.
iv. Height of Instrument must be measured correctly, as wrong antenna height will degrade the accuracy. If fixed rod is not used, Record the antenna HI in both **metric and imperial** (in meters as well as inches) to ensure an accurate HI. It is also recommended to manually record these antenna HI measurements for future verification.
v. Ensure that range poles and circular level vials are calibrated before beginning a survey.

2. Precaution about Tropospheric and Ionospheric Activities

Disturbances and variations in the atmosphere can affect RT accuracy and integrity to the extent of making the solution too inaccurate for surveying and engineering applications as well as preventing data link communication between the base station and the rover. Atmospheric conditions can vary in relatively small geographic regions as well as in short spans of time. The two layers that are commonly modeled are broadly categorized as the ionosphere and troposphere.

a. Charged particles in the ionosphere slow down and refract radio signals. It is a dispersive medium in that it affects different frequencies in a correlation to their wavelengths. Ionosphere is highly variable in space (geographical location) and time (solar cycle, seasonal, diurnal) and with solar-related ionospheric disturbances and earthquakes.
b. The troposphere affects Global Navigation Satellite System (GNSS) signals due to the variability of the refractive index. the “weather” in the troposphere refracts radio waves and the water vapor slows them down (wet delay), but not at the same rate as ionosphere. It is a non-dispersive medium because it affects all frequencies the same, but is site specific (or “geometrical”). If the residual tropospheric delay is not modelled carefully a bias error will occur in the vertical component.
c. Atmospheric conditions can cause enough signal “noise” to prevent initialization or, worse, can result in an incorrect ambiguity resolution. Basic precaution to minimize effect of Atmospheric conditions are

- **Avoid performing surveys when weather fronts are passing through the area.**
- It is also recommended that prior to departing to the project area, check on NOAA’s Space Weather Prediction Centre (SWPC) at http://www.swpc.noaa.gov/ to ensure that significant atmospheric disturbances (e.g. due to sunspots, or solar flares) are not predicted for

the time of the survey. These severe conditions can affect communications, GNSS tracking, and RTK/RTN results.

- Geomagnetic Storms: Disturbances in the geomagnetic field caused by gusts in the solar wind (the outward flux of solar particles and magnetic fields from the sun) that blows by Earth, may affect satellite orientation, orbital information, broadcast ephemeris, communication. These effects may cause surface charging which may cause inability to initialize for the GNSS user and radio problems.
  Recommendations: RTK Observation during level G3 - G5 storm events should not be carried out.
- Solar Radiation Storms: Elevated levels of radiation that occur when the numbers of energetic particles increase. Strong to extreme storms may impact satellite operations, orientation and communication. Due to which degraded, intermittent or loss of radio communication in the northern regions are possible and may impact the noise level at the receiver degrading precision.
  Recommendations: RTK Observation during level S4 - S5 storm events should not be carried out.
- Radio Blackouts: disturbances of the ionosphere caused by X-ray emissions from the Sun. Strong to Extreme storms may affect satellite signal reception. This may cause intermittent, degraded or loss of radio communication and increase noise at the receiver causing degraded precision.
  Recommendations: RTK Observation during level R3 - R5 storm events should not be carried out. Be aware of possible radio problems at level R2 storm events.

3. Guidelines for RTK Observation

I. Orientation

a. Antenna must be oriented to true north with the help of mark provide on the antenna. If there is no such mark provided on the antenna some other physical object like antenna cable port (in case of external antenna), power button can be used as reference mark for orienting the antenna to the true north.

II. Elevation Mask

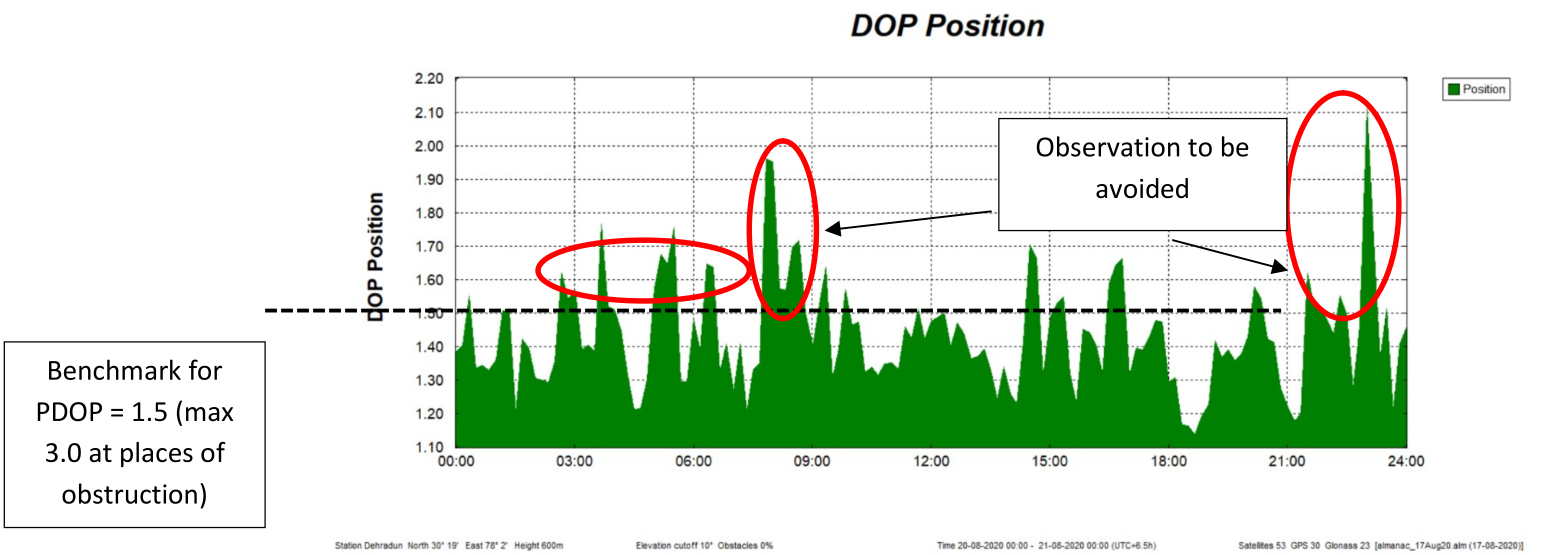
a. Set the elevation mask for Rover to **minimum 10$^{\mathbf{0}}$.** *It can be increased to 15*^{0}, in Urban Canopy area and Tree Canopy areas.

III. Multipath

a. Surveyed points should not be near reflecting surfaces like Water Bodies, Tin Sheds, glazed surfaces, Chimneys and other radio frequency sources like High Power Transmission Lines, Cellular Towers, FM radio stations and Microwave Towers etc.

IV. PDOP Mask

a. PDOP is a unitless measure of the satellite geometry relative to the GNSS equipment, It provides measures of the worsening of a GNSS solution. The lower the PDOP the better. Usually Manufacturer default GDOP/PDOP cut-off values are typically in the range 5-7. Reducing the GDOP/PDOP limit to 3 will increase the robustness of determined coordinates under challenging conditions (e.g. urban canyons etc).
b. Ensure the PDOP for dual constellation of (GPS+GLONASS) at the time of observation in the project area is less than 3.0.
c. Mission planning software can be used to determine optimal survey times i.e. time of lower DOP



V. Minimum number of satellites tracked

a. The recommendation is to configure the rover to track a minimum of six satellites for GPS only surveys, and seven to eight when doing GNSS surveys. The added benefit of tracking more satellites is that ambiguity resolution will generally be faster and more reliable.

VI. Occupation Time and Number of Observations at each station

a. The Occupation time and Number of measurements together define the time that the receiver is static while measuring a point. The criteria for both must be met before the point can be stored. The Occupation time defines the length of clock time for the occupation. The Number of measurements defines the number of valid sequential GNSS measurement epochs that meet the currently configured precision tolerance that must occur during the period of the occupation time.

b. When the rover is turned on and starts to track signals from the satellites it first measures a partial phase of the GPS carrier and then begins counting whole wavelengths. Initially, the receiver does not know the exact number of whole wavelengths between the satellite and receiver APC. Determining the full number of cycles between the receiver and the satellite is referred to as integer ambiguity resolution and is necessary for surveys that require cm level precision. For RTK, the rover receiver determines this integer number of cycles during initialization.

c. Occupation time after **gaining the initialization** should be at **least 120 sec** and Number of observation **minimum 20**. If communication is broken during this period, Re-initialize before recording measurement.

VII. **Solution Type**

a. Use only **FIXED** solutions

VIII. **RMS**

The values of Root Mean Square (RMS), is one of the Quality Check (QC) parameters, i.e. the parameters of accuracy and reliability of position determination. The RMS value depends on the observation time of the baseline and its length. High RMS values may indicate that disturbances have occurred, including the multipath phenomenon, among others. It can be expressed in distance units or in wavelength cycles. This is important as RTK measurements using only GPS signals are not recommended for RMS values greater than 70 millicycles

IX. **QC Values**

a. Many receivers also allow the user to set the horizontal and vertical QC values. These values are calculated internally by the receiver and give an indication of the precision of a single measurement. Typically horizontal and vertical QC values should be set to 2cm in Horizontal and 4 cm in vertical for Control work. For GIS Applications users can relax QC values.
b. Record QC1 & QC2 quality control information with each point measurement in RTK observations.

X. **Latency of correction data**

a. Network latency is the time it takes for data or a request to go from the source to the destination. Latency in networks is measured in **milliseconds**.
b. In case of Trimble Access
   i. Set the **RTK Mode** to **Synchronous**
   ii. When observation mode is **continuous topo,** disable store low latency positions, measurements hence obtained will be more accurate, and is more suitable when using continuous topo withtime-based tolerances.
c. If any other RTK application software is used, then set the latency to minimum possible. If the correction latencies are greater than 2 seconds or the communication link becomes intermittent the coordinate accuracy will suffer
d. Latency vary per user and from test to test within the same environment. The following factors affect the latency:
   i. Distance between the rover and the server
   ii. Operating system
   iii. Protocol overhead

XI. Survey Methodology

For GIS applications

a. For topographic survey, the use of a 5 second single window average will reduce the effect of individual coordinate solution variations.
b. Rod mount GNSS with or without bipod support can be used for GIS applications.
c. Please ensure that your rover unit is set to display all available coordinate quality indicators i.e. RMSE, Solution Type, No. of Satellite, PDOP and Latency of correction etc, for your position and pay close attention to them. In most of the situations these indicators reflect actual performance of your system, however in challenging conditions, (e.g. urban canyons, wooded area or area with high multipath or obstruction or with low satellite visibility etc), Quality indicators may be over-optimistic. Quality indicators for GPS+GLONASS tend to be slightly over-optimistic compared with their GPS-only counterparts in most environments.
d. Always use **integer-fixed solutions,** not ambiguity-float solutions.
e. CORS Services transmits Network RTK correction in all three Network RTK Method i.e. (VRS, MAC/AutoMax/i-MAX and FKP), which usually yield similar position accuracies, users can use any of three methods. **However users are advised to use survey method recommended by Manufacturer of their GNSS equipment.**

For Control point provisioning following additional guidelines should be adopted

a. At Each Control points Observation for 2 sets of minimum 3 minutes averaged windows (after initializations) in RTK/Network RTK mode should be taken.
b. There should be 45 to 60 minutes gap between these two sets and coordinate of both should be in agreement of better than 2 cm on horizontal and 5 cm in vertical.
c. For control point observation only tripod mount GNSS should be used. If it is feasible Tripod mount set should be kept on same setting for both the observations.
d. If coordinate of both sets are not in agreement, as point b, Static mode observation for 45-60 minute duration may be taken for post processing work.
e. For more precise control work, Static survey using post processing can be used.

4. Summary recommendation

a. Ensure communication and RTK/RTN corrections are available throughout project area.
b. Rover/Base Settings
   i. Elevation Mask of 10-15 degrees
   ii. PDOP should be less than 3

iii. Minimum number of tracked satellites set to six in GPS only and 8 in multi-constellation setup
iv. Mission planning software to determine optimal survey times
v. Use latest firmware recommended by the manufacturer
vi. Save ellipsoidal heights in rover
vii. Use only FIXED solutions
viii. Set receiver QC value to 1.5cm in Horizontal and 3 cm in vertical
ix. Data shall be collected only when the root mean square (RMS) is less than 70 millicycles.

c. Check initialization as often as practical.
d. Monitor the continuity, completeness, and latency of RTK/RTN incoming data.
e. Avoid surveying when a weather front is passing through the survey area.
f. Check the space weather forecast and use caution when working during increased ionospheric activity.
g. Ensure GNSS is interoperable by mixing equipment from different manufacturers.
h. Re-initialize after loss of communication and verify on a known or previously determined point.
i. Monitor SNR values during survey.
j. Data streaming should be done in open standard RTCM format.
k. QC1&QC2 Quality indicators should be recorded

References

1. NGS User Guidelines for Single Base Real Time GNSS Positioning version 3.1 [https://geodesy.noaa.gov/PUBS_LIB/UserGuidelinesForSingleBaseRealTimeGNSSPositioningv.3.1APR2014-1.pdf]
2. NGS Guidelines for Real Time GNSS Networks version 2.2 [www.ngs.noaa.gov/PUBS_LIB/NGSGuidelinesForRealTimeGNSSNetworks.pdf]
3. NRC Guidelines for RTK/RTN GNSS Guidelines for RTK/RTN GNSS Surveying in Canada version 3.1 [www.nrcan.gc.ca/earth-sciences/geomatics/csrs-publications/9056]
4. ICSM Guideline for Control Surveys by GNSS Special Publication 1 version 2.1 [https://www.icsm.gov.au/publications/standard-australian-survey-control-network-special-publication-1-sp1]
5. ISO 17123-8 Optics and optical instruments – Field procedures for testing geodetic and surveying instruments – Part 8: GPS field measurement systems in real time (RTK) [https://www.iso.org/standard/62961.html]
6. TSA Guidance Notes for GNSS Network RTK Surveying in Great Britain [https://www.tsa-uk.org.uk/downloads/]

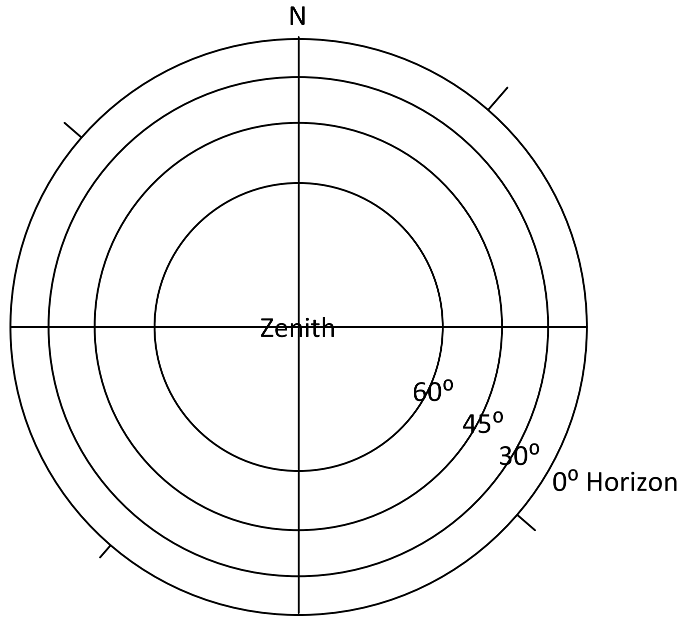
Annexure- A

Log Sheet for RTK Occupation

Coordinate System: WGS84/UTM Zone ____

S. No.	Parameters	Recommendations	Input/Selection/Remarks	
			Set 1	Set 2
	Antenna Id	-		
1	**Date and Time of the Observation**	-		
2	**Station Code**	-		
3	**Project area classification**	-		
4	**Orientation of Antenna**	Orient towards North		
5	**Height of Instrument (in m and ft)**	-		
6	**Elevation Mask**	10^0		
7	**PDOP Mask**	3		
8	**Precision Control for Horizontal and Vertical**	For control work 2 cm (Horizontal) and 4 cm (Vertical)		
9	**Minimum number of satellites tracked**	6		
10	**Occupation Time and Number of Observations**	120 sec, 20 Nos		
11	**No of Sets of Observation at each point**	1 set for GIS application and Min 2 sets for control work		
12	**Latency (at the time of starting)**	<2000 ms		
13	**Initialization time (sec)**	<5 sec		
14	**Easting in Mt**			
15	**Northing in Mt**			
16	**Ellipsoidal Height in Mt**			
17	**Weather Condition (brief description)**	-		

18 Obstruction Chart



Shade Sky under obstruction

19 Sketch