Guidelines for RTK/RTN GNSS Surveying in Canada

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Guidelines for RTK/RTN GNSS Surveying in Canada

Surveyor General Branch

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Foreword

This set of guidelines for Real Time Kinematic (RTK)/Real Time Network (RTN) Global Navigation Satellite System (GNSS) surveying has been prepared to assist the surveying community in Canada through sharing what we view to be best practices. The guidelines have been prepared in response to needs expressed by the Federal, Provincial, and Territorial members of the Canadian Council on Geomatics (CCOG).

The work was coordinated by the Canadian Geodetic Reference System Committee (CGRSC), a sub-committee of CCOG, and the guidelines were developed by a team from different agencies, Federal and Provincial. A number of other individuals, agencies, and professional land surveying associations in Canada have also contributed to this effort, and we wish to thank them for improving this product. Although the authors strove for accuracy, please let us know if you find any errors or omissions and we will amend the text accordingly in future versions.

Special thanks to Brian Donahue, Geodetic Survey Division; Jan Wentzel, Surveyor General Branch; and Ron Berg, Ministry of Transportation Ontario; for their leadership in completing this project, and to all the CGRSC members who provided valuable feedback throughout the process.

We sincerely hope that these guidelines make a positive contribution to surveying in Canada.

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Table of Acronyms

- **APC:** Antenna Phase Center
- **ARP:** Antenna Reference Point
- **CACS:** Canadian Active Control System
- **CBN:** Canadian Base Network
- **CSRS:** Canadian Spatial Reference System
- **CSRS-PPP:** Online Precise Point Positioning (PPP) Service
- **GDOP:** Geometric Dilution of Precision
- **GLONASS:** *Globalnaya Navigatsionnaya Sputnikovaya Sistema* or Russian Global Navigation Satellite System
- **GNSS:** Global Navigation Satellite System
- **GPS:** Global Positioning System
- **HI:** Height of Instrument. In RTK this refers to the distance from the physical point to the Antenna Reference Point (ARP)
- **HPN:** Provincial High Precision Networks
- **NAD83:** North American Datum 1983
- **PDOP:** Positional Dilution of Precision
- **RINEX:** The Receiver Independent Exchange Format
- **RTK:** Real-Time Kinematic
- **RTN:** Real-Time Network

1. Introduction

Real-Time Kinematic (RTK) surveying using Global Navigation Satellite Systems (GNSS) is now a common method used for both cadastral and engineering surveys in Canada. In recent years the number and extent of public and private Real-Time Networks (RTN) in Canada has been rapidly increasing. RTN surveys are becoming more popular where available, but RTK surveys are still the only option available in many parts of Canada. To see the current RTN coverage in Canada, refer to the coverage map in Appendix D.

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 Professional Surveyors with a set of concise and easy to follow best practice guidelines for achieving centimetre level RTK/RTN surveys. This document contains recommendations for all aspects of RTK/RTN surveying, including a comparison of RTK and RTN methods. Additional recommended references and web links have also been included for users. This document serves as a reference, as well as a reminder of what is important. Appendix B includes a comprehensive field checklist that can be modified to an individual's specific requirements when doing RTK/RTN surveys, while Appendix C lists important questions that a RTN user should ask their provider as part of their project planning.

These guidelines were developed by a working group which included: Brian Donahue from the Geodetic Survey Division (GSD) of Natural Resources Canada, Jan Wentzel from the Surveyor General Branch (SGB) of Natural Resources Canada, and Ron Berg from the Ministry of Transportation for the Province of Ontario (MTO). The recommendations in this document are based on a combination of author experiences, guidelines from other agencies, and theoretical studies.

Throughout this document the following terms are used:

- **Users**: Anyone performing either RTK or RTN surveys.
- **GNSS**: Global Navigation Satellite System and will be used to describe GPS, or GPS+GLONASS (as well as other systems (e.g. Galileo) as they come online). Users should generally apply the same practices whether using GPS only or GNSS. The main advantage of GNSS is the increased number of satellites which may improve the geometry (especially when working in urban canyons or other partially blocked areas).
- **RTK**: Single-base Real-Time Kinematic GNSS surveys.
- **RTN**: Real-Time Network GNSS surveys. Also used to describe the network of real-time base stations. RTN is also known as Network RTK (NRTK).
- **Reference System**: The term *reference system* is used in a general sense to describe a geographic coordinate system.

- **Reference Frame:** The term *reference frame* is used to describe a specific reference system. In Canada the official reference frame is NAD83 (CSRS). A reference frame may also have different versions (or realizations) and epochs associated with it. For NAD83 (CSRS), the adopted versions (epochs) as of June 2015 are summarized in Appendix A.

2. RTK/RTN Surveying Overview & Description

RTK surveying is a relative positioning technique which measures the position of two GNSS antennas relative to each other in real-time. One antenna is setup on a static point with fixed coordinates and is known as the base station. The RTK base station transmits its raw observations to the rover(s) in real-time and the rover uses both the rover and base observations to compute its position relative to the base (see figure 2-1).

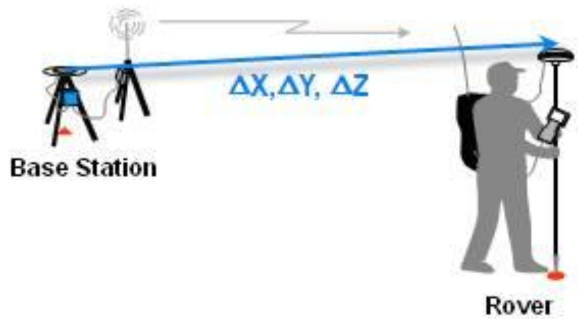

Figure 2-1 *Typical RTK Setup*.

After a short initialization time (often less than a minute) the rover can continuously determine a precise 3D vector relative to the base station. This type of surveying requires a reliable communications link between the base and rover as the rover needs continuous observations from the base. When working with short baselines (<10 - 20km), in open sky areas, and with good satellite geometry these relative 3D baselines can be determined to several cm (or better).

RTK has proven to be a reliable and efficient means for determining precise relative baselines. However, this method is limited to baselines of approximately 10 – 20km due to the effect that distance related errors (atmosphere and satellite orbits) have on the ambiguity resolution (initialization) and solution precision. The precision of RTK decreases as the baseline length increases. Real-Time Network (RTN) surveying has been developed to extend this base-to-rover range limitation. The RTN concept is that a group of reference or base stations collect GNSS observations and send them in real-time to a central processing system. The central processor then combines the observations from all (or a subset) of the reference stations and computes a network solution. From this network solution the observation errors and their corrections are computed and broadcast to rovers working within the bounds of the RTN. There are several different RTN approaches in use including the virtual reference station (VRS), master auxiliary concept (MAC), and Flächen Korrektur Parameter (FKP). For more information on the different RTN approaches the reader is encouraged to check their manufacturer's documentation, or to check some of the references in this document.

2.1 RTK vs. RTN

This section compares the major differences between working with RTK and RTN. Both methods can provide relative 3D accuracies of 1 to several cm and most of the differences are related to increased productivity and reduced cost.

Base Station

Working with RTK requires the purchase, maintenance, monitoring, and setup of one or more base stations. This can be both time consuming and costly, as well as technically challenging for novice users. Working with RTN allows the users to leave the burden of setting up, maintaining, and monitoring the base station(s) to the network operator. The RTN user is required only to purchase a network subscription for access to the base stations. For some expert users however, working with their own base station(s) does allow for more control over the technical aspects of the base station setup and correction delivery.

Communications

RTN operators normally use cellular phone networks. This means that corrections can only be received where cellular coverage exists. RTK surveys normally use UHF, VHF or broad spectrum radios. This removes the reliance on cellular coverage but limits the baseline length to the range of the radio link making RTK surveys over large areas challenging.

Solution Quality

The precision of RTK decreases as the baseline length increases. RTN has been developed to extend this base-to-rover range limitation and will give comparable results anywhere within the polygon of the network up to about 50km from a base station. To achieve the same accuracy with RTK it might be necessary to set up multiple base stations or to use a leap frog method with relatively short baselines, both of which will increase the cost and reduce the efficiency of the survey.

2.2 RTN Issues

Working with a public or private RTN can be a very precise and efficient way to perform cadastral and engineering surveys. This can however lead to erroneous results if the RTN user is not aware of some important details of the RTN. As mentioned in section 2, RTK/RTN surveying determines the position of the roving antenna relative to the base station(s). In the case of RTN solutions, the rover position is determined within the reference frame of the network as determined by the fixed coordinates of the network base stations. The user needs to know what reference frame is used by the network provider. Good communication with the network provider is essential to know this information. It is the responsibility of the user to ensure their results are properly aligned to the required reference frame. In most cases it will be necessary to verify the accuracy of their RTN derived rover positions by measuring to known points in the user's required system.

In Canada the official reference frame is NAD83 (CSRS) but it is important to know what version and epoch of NAD83 (CSRS) is required for your survey. There are different versions (and reference epochs) of the official reference frame which have been adopted in Canada. Appendix A summarizes the evolution of the CSRS and the adoption of the CSRS within Canada as of June 2015. In addition to working with different versions of NAD83 (CSRS) there may also be cases where the user is required to work in a completely different local reference system. In this case the user will need to calibrate their survey using the procedure found in section 4.4.

Another important issue to consider when working with an RTN is whether the network operator is performing any integrity monitoring of their base stations.   This integrity monitoring should include both a confirmation on the stability of the network base stations, as well as a report of any station outages. A discontinuity in the fixed coordinates for one or several network base stations will be passed on directly or partially to the user in their rover positions while an outage of a base station could degrade the user solution if there are no alternate stations within the recommended 50km range. It is recommended that users request a confirmation of the reference frame, a report of coordinate stability, and a notice of any station outages from their network provider.

2.3 RTK Issues

Many of the issues discussed in section 2.2 are also important when working with RTK. The difference with RTK is that the responsibility generally lies with the user to ensure the quality of the base station, the base station metadata, and the integrity of the base station coordinates. There are some instances where a user can access RTK corrections from another source such as an Active Control Point (ACP) but these are rare due to the sparse spacing and quantity of ACP stations broadcasting real-time corrections in Canada. Appendix D contains a map of the currently (May 2015) available public RTK stations in Canada.

2.3.1 Site Conditions

When installing an RTK base station the user should be familiar with the chapter 4 recommendations for using an RTK rover. Many of the issues which are important for the rover are even more important for the base station setup. In addition, there are several other important considerations when installing an RTK base station. These include sky visibility, stability of base setup, and access to the desired reference frame.

The importance of each of these issues needs to be considered when deciding where (and how) to set up a base station.

RTK surveying requires common satellites to be observed at both the base and rover antennas. To take full advantage of the base station observations it is necessary that the base antenna has an unobstructed view of the sky above 10-15 degrees. It is much better to establish a new station with good satellite visibility than it is to try to occupy an existing reliable, well known monument with poor sky visibility (Henning, 2011).

As with any type of GNSS survey the base station stability (repeatability) is very important. The following steps should be taken to ensure repeatable positions for the base station.

- Temporary base stations should be installed in a stable environment with calibrated centering, levelling, and HI measuring equipment.
- The base station HI should be measured and recorded in both metric and imperial.
- Receivers should be configured to save raw observations which can be processed using CSRS-PPP or with the vendor software to verify the stability of the setup.

2.3.2 Base Station Coordinates

Access to the desired reference frame is another important consideration when installing an RTK base station. There are three approaches to accessing the desired reference frame. The first is to setup on a known point, the other two options require setting up a new base station and establishing coordinates.

Occupy Existing Control

When possible the preferred choice to access the reference frame is to setup the base station on an existing control point of sufficient accuracy. This could be a CBN, HPN, or lower order control point. Any time a user sets up on existing control it is recommended to tie into other existing control in the area to verify the coordinates of the base station. Another good practice is to record raw observations in the base station and post process these data to verify the setup.

Relative Carrier Phase Processing

When there are no usable control points in the immediate survey location to set the base station on, but control exists within 30-50km it is possible for the user to establish local control relative to these known control points by static GNSS survey methods. This can be done by computing redundant GNSS baselines with post-processing software. When establishing control for RTK base stations it is important to follow the guidelines in this document (see sections 4.3 and 4.4) and to have the receiver save raw observations so that the estimated coordinates can be computed using post-processing software.

Precise Point Positioning (PPP)

Many GNSS users are now using PPP to establish control. This is especially useful in remote areas where accurate control does not exist. However, even when control does exist within a reasonable distance it is sometimes advantageous to use PPP to establish new control. In Canada, there is a free online service operated by the Geodetic Survey Division (GSD) of Natural Resources Canada called CSRS-PPP. Figure 2-2 shows the typical flow of a CSRS-PPP job.

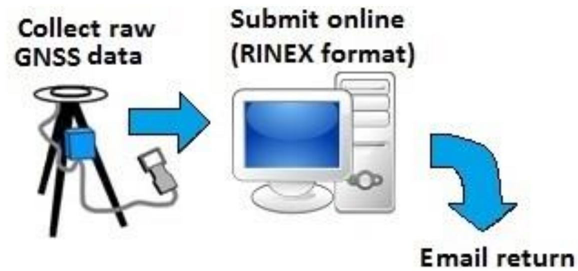

Figure 2-2 *CSRS-PPP Overview.*

CSRS-PPP allows the user to submit a RINEX format data file and get back computed positions, standard deviations, and processing reports. The user must verify the antenna type and HI in the RINEX file header as the computed position is for the antenna phase centre (APC), and the software requires the antenna type and HI to derive the position of the marker. The user must also ensure they collect and submit a sufficient amount of GNSS observations to meet their accuracy needs (See for example Berg and Holliday, 2011). As a minimum, the user should check the standard deviations of the computed positions to ensure the desired accuracy is obtained. It is also good practice for the user to become familiar with the processing reports to ensure the quality of their positions. More details about CSRS-PPP can be found in (Tétreault and Sauvé, 2010).

Notes about CSRS-PPP:

- User has the choice of selecting NAD83 (CSRS) reference frame at various epochs, and orthometric heights in either the CGVD28 or CGVD2013 vertical reference frames.
- As with other types of GNSS surveying, the accuracy of the positions will be affected by equipment, location, occupation times, and environmental conditions.
- Due to the availability of precise orbit and clock products, GPS only solutions can be determined 90 minutes after data acquisition while GNSS solutions are determined the following day.
- Typically 12-24 hours of dual-frequency GNSS observations can achieve centimetre level accuracy, while 2-4 hours can achieve < 5 cm accuracy, and 1-2 hours can achieve < 10 cm accuracy.

3. Project Planning

This section of the guidelines specifically deals with the planning required to conduct an RTK/RTN survey. It is assumed that, as part of any positioning survey, the user has already determined:

- The reference frame to be used
- The accuracy required

3.1 Theoretical Suitability

Given the positioning requirements of the project (accuracy, reference system, etc.), it is part of the user's responsibility to determine if RTK/RTN methods and technology will provide those results. There may even be instances where only part of a project is suitable for RTK. An example might be a project where the horizontal accuracy is suitable for RTK but the vertical accuracy requirements can only be achieved using spirit levelling (CRGB, 2009).

In order to determine this, users should refer to:

- Technical specifications supplied by the equipment manufacturers.
- Information supplied by RTN service providers.
- Independent research and documentation on the capabilities of RTK/RTN systems.
- Results of validation testing of the user's particular equipment configuration.
- The user's personal experience gained through the repeated use of the equipment under varying conditions.

This information will help users determine:

- If RTK/RTN methods will be able to achieve the required results.
- The type of RTK/RTN equipment, and configuration to use.
- The field methodology to follow.

3.2 Practical Considerations

Once it has been determined that an RTK/RTN survey should be able to achieve the required results for the project in theory, there are a number of other project specific elements that must be considered from a practical sense.

3.2.1 Area of project

Unique project specific site conditions may dictate that RTK/RTN is not the appropriate tool to use. Project areas consisting largely of forests or tall concrete buildings (urban canyons) may make it impossible to achieve any results, let alone results meeting the required accuracy due to satellite and/or communication blockage. Even if forests or urban canyons are not an issue, individual sites within the project should be evaluated to avoid obstructions that would block satellite signals, or sources of multipath that would reflect signals.

Where an RTN exists, it is important for users to be aware of the extent of the RTN and where their project lies within that network. Accuracy rapidly declines the further a survey project lies outside the umbrella of an RTN (Henning, 2011a).

In most RTK/RTN surveys it will be necessary to occupy existing control points either for base stations or for verification of the RTN computed positions. Project planning should include gathering as much information as possible with respect to the location of these control points to aid field staff in locating control while in the field.

3.2.2 Communication

Key to a successful RTK/RTN survey is the communication between the base and the rover(s). For RTN surveys the most common method of communication is through cellular phone networks. RTN service providers should be consulted to determine optimum configurations of hardware and software required to fully utilize the services provided. They should also be able to provide guidance with respect to maximum ranges within or outside the network and any unique areas of outages or weak service.

For RTK surveys, communication between the base and the rover is usually through UHF, VHF or broad spectrum radios. Equipment manufacturers can supply information with respect to maximum ranges however results experienced in the field can vary due to things such as terrain. More than one base station may be required for a particular project area because of radio communication limitations. Comprehensive user knowledge of the limitations and maximum ranges of their particular communication system will dictate network design and in particular the number of base stations required and their optimum locations.

3.2.3 RTN Base Stations

The RTN service provider should be contacted prior to the project to confirm the service status. The user should confirm the current reference frame being used and inquire about any changes to the hardware, software, base station coordinates or other service delivery components since the last time that the service was used. Any required hardware or software updates recommended by the provider should be investigated. Service provider contact information should be provided to field personnel so they can ensure that the service is operational at the time of survey.

3.2.4 RTK Base Stations

A number of factors must be considered with respect to an RTK base station. The use of a known CBN, or HPN station, with a forced centering plate on a pillar would be ideal. However, these points are rarely close enough to the project site and in most cases only secondary control points are available. There will also be cases where no suitable control points are available and local control must be established on site. In all cases, the user should consider the following criteria for base station selection.

- Coordinates and accuracy of known points – are they consistent with those required for the project?
- Is the selected base station site accessible, stable and clear to the sky?
- Is the base station site in a secure area? Can it be left alone or will it need supervision?
- How will a local base station be positioned? Section 2.3.2 gives a few common methods.

3.2.5 RTK/RTN Rovers

Rover equipment including radio communication equipment should be checked to ensure that the manufacturer's recommended firmware and software are being used. Given the size of the project, the number of Rovers required to complete a project within a certain time frame must be evaluated.

3.3 Project Configuration

Given the number of stations to be positioned, accessibility, base stations to be used, communication or RTN range limitations it would be wise to prepare a field logistics plan so that all members of the crew are aware of what is expected of them as a group and as individual crew members.

To achieve maximum measurement efficiency, each receiver operator should be supplied with an individual plan that itemizes:

- Which points will be occupied
- Survey procedures (see section 4.3)
- Information to be recorded manually
- Access issues
- Point descriptions
- Timing constraints

4. Survey Procedures

This chapter outlines the procedures to be followed during an RTK/RTN survey. The chapter is divided into 4 sections with section 4.1 describing how to best set up the rover. Section 4.2 talks about initialization of the rover and how to mitigate errors related to the survey environment. Section 4.3 describes procedures during the field survey and finally section 4.4 discusses post processing and reference system issues.

4.1 Equipment Calibration & Setup

As with traditional GPS surveys it is important to ensure proper calibration of all equipment before starting a survey. With RTK/RTN surveying it is also necessary to ensure the rover (and base if applicable) has been set up with the desired settings for the current project. Even when no known rover configuration changes were made it is necessary to confirm the setup. Things such as a receiver firmware update could unknowingly reset some rover settings to the factory default.

4.1.1 Rover Receiver Settings

Before beginning an RTK/RTN survey it is important to ensure that the rover is configured in the best possible way to achieve the desired accuracy. There are several important settings which need to be saved in the rover.

Satellite Tracking

Three related settings which are configurable in most receivers are the elevation mask, the minimum number of satellites tracked, and the maximum PDOP (Positional Dilution of Precision). PDOP is a unitless measure of the satellite geometry relative to the roving receiver. The lower the PDOP the better and it is recommended to set the maximum PDOP to 2-3 in the receiver.

The elevation mask sets an elevation angle in the receiver below which the receiver will not track GNSS signals. This should be set to a minimum of 10 degrees and preferably to 15 degrees since signals traveling close to the horizon have the longest path through the atmosphere, have a lower Signal-to-Noise Ratio (SNR), and are more affected by local multipath conditions. Increasing the elevation cutoff higher than 15 degrees can reduce the number of satellites tracked and increase the PDOP to a higher than desired level.

A minimum of five satellites are required for RTK/RTN surveying (six when combining GPS and GLONASS satellites since the GPS/GLONASS system time offset must also be resolved). Studies have shown that a minimum of seven GNSS satellites will give more accurate results (Aponte et al., 2009). 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.

Mission Planning

Even with both GPS and GLONASS now having fully operational constellations there are still times during the day when the number of satellites visible above 15 degrees in a particular area may be as low as four (GPS only). It is important to use your equipment manufacturer's mission planning software to determine the best time to perform RTK/RTN surveys in your area. Most mission planning software will also allow you to set azimuth and elevation masks to simulate working in environments where the horizon is not clear. When working in urban canyons it is recommended to use GNSS capable equipment and to use mission planning software to determine the optimal time to perform your survey.

Interoperability

Users should also ensure that their GNSS equipment is interoperable when mixing equipment from different manufacturers. This can be verified by the RTN operator or the equipment vendor. To ensure interoperability it is recommended to keep your receiver firmware updated with the latest recommended version from the manufacturer.

When working with mixed equipment from different manufacturers it is also important to verify that the rover is correctly interpreting the antenna type string being broadcast by the service provider and that there is a matching antenna phase center model in the rover. This includes the different NULLANTENNA types used by station operators in cases where they reduce their raw observations to the antenna ARP and broadcast a NULLANTENNA type to the end user. It is recommended to communicate with the service provider to ensure the antenna type being broadcast from the base station(s) has a matching antenna phase center model in your rover. Information and absolute calibration models can be retrieved from the National Geodetic Survey (NGS) website at http://www.ngs.noaa.gov/ANTCAL/.

Orthometric and Ellipsoidal Heights

In order to get real-time orthometric heights, a geoid model or height transformation must be loaded into the rover. A new vertical reference frame, the Canadian Geodetic Vertical Datum 2013 (CGVD2013) was adopted in Canada in November 2013 and superseded the Canadian Geodetic Vertical Datum of 1928 (CGVD28) as the official vertical reference frame in Canada. The CGVD2013 is accessed using the CGG2013 geoid model which must be selected in the rover. In many cases users may wish to continue working in CGVD28 which will co-exist with CGVD2013 for the foreseeable future. In these cases the vertical reference frame can be accessed using the HT2 hybrid geoid model. This model transforms ellipsoidal heights to orthometric heights by applying a geoid model which has been distorted to fit the CGVD28 benchmarks. When working with orthometric heights users should verify and note which vertical reference frame is selected in the rover.

In local areas where the geoid model may not meet the accuracy requirements of the project there may also be a need to calibrate the heights to local vertical benchmarks (see section 4.4.2). The user must apply one of the official transformations (HT2_0 or CGG2013) or a local vertical calibration if there is a requirement for real-time orthometric heights. It is also recommended to save ellipsoidal heights which can be transformed to any vertical datum in post processing.

RTK Solution Type

Another parameter which should be set in the rover receiver is the RTK type to use. It is recommended to use only **FIXED** ambiguity solutions where the integer phase ambiguities have been resolved. Never use float or DGPS solutions for any kind of survey work. The accuracy of float and DGPS solutions will be in the meter level and should only be used for low accuracy work. If the rover unit displays the RTK age it is also important to monitor this value. If the RTK age (latency of corrections) is older than a few seconds it might indicate communication problems and the results will need to be used with caution.

QC Values

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 1 cm for control points and 2-3 cm for topographic points.

4.1.2 Rover Antenna

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 must 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/.
- Record the antenna HI in both metric and imperial (or use a fixed height pole) to ensure an accurate HI. It is also recommended to manually record these antenna HI measurements for future verification, and to verify these measurements in the field.
- It is also important to record the Antenna Reference Point (ARP) used, and the antenna type manually.
- Ensure that range poles and circular level vials are calibrated before beginning a survey.
- Use a tripod or bi-pole when more accurate positions are required.

Another important piece of equipment which should be checked before beginning a survey is the antenna cable. Loose cable connectors, or kinked cables will lead to noisier signal reception and can cause loss of signals for low elevation satellites, higher code noise, incorrect ambiguity resolution and erroneous results.

4.2 Rover Initialization & Survey Environment

The following sections describe issues related to resolving the integer number of carrier phase wavelengths from each satellite to the rover (so called RTK initialization), as well as problems caused by environmental conditions.

4.2.1 RTK Initialization

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. The two most common methods used to resolve the ambiguities are explained below.

On-The-Fly (OTF)

On-the-fly initialization requires a minimum of five common satellites tracked by the base and the rover and allows the user to be moving while the ambiguities get resolved. Once the ambiguities are resolved and a **FIXED** solution is obtained, the user should re-measure a known or previously determined point to verify the initialization. If there are no known points nearby the user should measure a point, re-initialize and check in to the initial point. Re-initialization requires complete loss of lock to all satellite signals.

Known Point

With known point initialization, the user enters known coordinates into the rover and initializes while stationary over the known point. This method can be used to verify the initialization by comparing the measured position of the point after initialization to its known coordinates. If the system fails to initialize in a normal amount of time then the user should verify that the input coordinates are correct, and that the location is not in a high multipath environment. It might also be necessary to move to a new location and try initializing using OTF.

Under normal conditions the ambiguities should be resolved in less than 1 minute. It is good practice to monitor how long it takes to obtain a fixed solution and if 1-2 minutes is exceeded then a new independent fixed solution should be obtained. It is also good practice to regularly re-initialize and re-measure known or previously measured points during the survey to verify the validity of each new initialization. Many receivers continuously compute new initializations during the survey as a validation tool. Users should observe all important points at least twice, with independent initializations as a validation.

4.2.2 Environmental Error Sources

There are several environmental factors that can reduce the precision and/or accuracy of RTK/RTN derived positions. These can include site specific factors such as signal blockage and multipath; or atmospheric factors such as tropospheric and ionospheric errors.

Signal Blockage
When performing an RTK/RTN survey in any environment that does not allow a clear view of the sky (e.g. urban canyon, forest), the user must be aware of the effect of signal blockage on the results. GNSS signal blockage is a common problem when performing RTK/RTN surveys under tree canopy and can weaken the satellite geometry, lengthen the time required for a solution to initialize, and cause erroneous positioning. When working in partial sky blocked environments the use of multi-constellation equipment can help overcome the problem of signal blockage. However, the user should monitor the SNR, and PDOP values, and be aware that RTK/RTN may not be a suitable technique.

Multipath
Multipath is the relative phase offset or time delay between directly and indirectly received radio signals (GSD, 1992). When GNSS signals are reflected off nearby structures and reach the antenna via an indirect path there is an increase in the range error. Multipath errors over a short period of time can go undetected in the receiver and cause position errors unknown to the user. As a result, users should re-occupy important points with a new initialization after a suitable amount of time has passed and the satellite geometry has changed.

Tropospheric Errors
The troposphere is the neutral atmosphere from the Earth’s surface to about 10km altitude and causes a frequency independent delay on GNSS signals. RTK differences the tropospheric delay between the base and rover, so users should be aware that differences in elevation or atmospheric conditions between the base and rover can cause a relative troposphere bias which will cause a bias of the estimated height of the rover. RTK users should keep the base and rover at similar elevations and to avoid performing surveys when weather fronts are passing through the area. RTN strategies seem to be able to mitigate most of the residual troposphere errors due to rover elevation differences (Edwards et al., 2008), but RTN users should still avoid working when a weather front is passing through the project area.

Ionospheric Errors

The ionosphere is the upper part of the atmosphere and (unlike the troposphere) is dispersive (frequency dependent). Dual-frequency GNSS systems take advantage of the dispersive nature of the ionosphere and during normal conditions are able to calculate and remove the majority of the bias. For this reason it is recommended to only perform RTK surveys with dual-frequency receivers. It is also recommended that prior to departing to the project area, check on either NOAA's Space Weather Prediction Centre (SWPC) at http://www.swpc.noaa.gov/ or NRCan's Space Weather Canada at http://www.spaceweather.gc.ca/ 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. This is something that users are better equipped to determine with experience and knowledge of their particular equipment and area of work.

4.3 Field Survey

This section discusses some practical considerations when performing RTK/RTN field surveys. These considerations include various rover outputs which can be monitored to ensure quality and precision, as well as applying techniques to ensure accuracy through redundancy, validation, and calibration.

4.3.1 Communications

The quality of the communication link and the age of corrections should be monitored during the survey. Accurate RTK/RTN positioning requires a full and complete set of correction messages. If the correction latencies are greater than 2 seconds or the communication link becomes intermittent the coordinate accuracy will suffer (Henning, 2011a). After communication outages the user should verify the initialization by re-initializing the solution and checking on a previously measured (or known) point.

4.3.2 Rover QC Indicators

When performing RTK/RTN surveys it is important for the user to be familiar with the various quality indicators that are normally displayed by the rover. Many of these QC measures can have tolerances configured in the rover, outside of which the observed points will be rejected. The user should be familiar with the recommendations in section 4.1.1 before configuring the receiver. The following receiver indicators should be constantly monitored during a survey.

- Status of the initialization should remain **FIXED**.
- Coordinate Precision (QC value) should be monitored to ensure that both the horizontal and vertical precision is satisfactory.

- If possible, the coordinate quality threshold should be set slightly lower than the precision required for the survey. Do not set the QC threshold significantly lower than the desired precision or a significant number of observations may be rejected. This will lead to longer than necessary observation times at each point (Bisnath, 2011).
- The user should monitor the SNR values calculated by the receiver. Different manufacturers display the SNR values differently so the user will need to consult their manual and use experience to determine the normal range. The SNR values can be useful to diagnose multipath errors, atmospheric disturbances, and initialization issues.

4.3.3 Quality Control

As with any measurement technique, repeated measurements are required for an accurate and reliable solution. The receiver quality indicators are useful in alerting the user of potential problems but the user must also take steps to minimize the random and systematic errors associated with RTK/RTN surveys. All points determined by RTK are single vectors radiating from the base (physical or virtual) to the rover. Some quality control should be incorporated to check the reliability of the results. The degree of checking is dependent on the importance of the point being surveyed. For instance, a project control point is much more critical than an individual shot on a topographic feature. Therefore the quality control procedures should account for such circumstances (Berg, 1998).

Time Window Averaging

Most receivers will allow the user to compute a mean position over a specified time period (time window averaging). Studies have shown significant benefits of time window averaging on the precision of computed positions (Bisnath, 2011, Edwards et al., 2008). Control points should use a time window average of at least 1 minute, topographic points at least 5 seconds, and until the desired QC indicators are achieved. For topographic surveys, the use of this 5 second window average will reduce the effect of individual coordinate solution variations (Edwards et al., 2008). For precise work such as control station establishment, longer time windows of up to 5 minutes should be used.

Re-Occupation

Time window averaging on its own is not enough to provide an accurate and reliable solution. All the individual epochs in the time window are still relying on the same initialization and have had very little geometry and atmosphere change. So for important points it will also be necessary to re-observe after a suitable time has passed and with a new initialization (double windowing). To take advantage of changes to the satellite geometry and atmospheric conditions, a window separation of 1-2 hours is recommended, however a separation of only 20 minutes has shown to improve the coordinate accuracy by 10 – 20% (Edwards et al., 2008). A further advantage of the double window averaging is that it can also detect human blunders related to the station metadata and/or setup. If a fixed height rover is not used then changing antenna heights at the rover between measurements provides a check on the largest source of human error in GNSS surveying – recording incorrect antenna heights. For control points the minimum recommendation is two separate time windowed observations with unique initializations and a time separation of at least 20 minutes.

Checks to Known Control

Another important aspect of a quality survey is determining the accuracy. The receiver QC values, redundant measurements, and time window averaging are all useful in determining and improving the precision of the survey. The accuracy of the survey will also need to be verified to ensure there are no biases between the survey and the project reference system. The accuracy of the survey can be determined by performing checks to well known or accurately determined points. These ties to known points will also help to eliminate any human blunders. The recommendation is to survey known points after initialization and compare the coordinates. The coordinate differences should be within the accuracy requirements of your survey. When there is no local control available, it is recommended to establish control by running a static session and using one of the methods described in section 2.3.2. These check points should be surveyed as a minimum at the start and end of the survey, and any time communications or initialization is lost. Since many equipment sets are continuously checking the initialization and re-initializing it is important to check into known points as often as practical.

4.3.4 RTK Base Station Quality Control

When working with RTK, the user is responsible to verify not only the quality of the rover positions but also the quality of the base station setup. The best check is to establish multiple base stations and to alternately measure each rover point from each of these base stations. This provides verification on all factors in the point determination: base station setup, base station (reference) coordinates, rover setup, antenna heights, and GNSS measurements. This method ensures the highest confidence but takes the longest to carry out (Berg, 1998). If this is not practical then the quality control recommendations (section 4.3.3) should be followed as a minimum.

4.4 Post Processing

4.4.1 Horizontal Calibration

When working with RTK/RTN it is necessary to ensure the computed coordinates are compatible with the desired reference frame. If the coordinates are not compatible then an empirical fitting of field RTK measurements to published control monument coordinates is required. This fitting is known as a local **transformation** or **calibration** (MTO, 2006).

The following steps are recommended to ensure this compatibility:

- Communicate with the RTN operator to determine what reference frame they are using for their solution.
- If doing RTK verify the reference frame for the base station(s) coordinates.
- If the RTN or base coordinates are referenced to NAD83 (CSRS) but the wrong version or epoch, then transform the computed coordinates to the epoch of the desired version (using TRX). TRX software is available online from NRCan/GSD at http://webapp.geod.nrcan.gc.ca/geod/tools-outils/trx.php
- After ensuring coordinates are in the proper epoch, measure the RTK/RTN position of as many known points as practical.
- If the published coordinates do not fit with the measurements to known points a local calibration can be done. This calibration will require a minimum of four points well distributed around the local project area.

In some cases, it may be better to skip directly to the last step and estimate and apply parameters from a calibration to transform the RTK positions into the official reference frame of the known control. This approach is sometimes more preferable locally than applying a transformation based on official reference frame transformation parameters since there can be biases in the existing local control points (Bisnath, 2011).

4.4.2 Vertical Calibration

Using the ellipsoidal heights determined in the correct NAD83 (CSRS) epoch, the user can transform to orthometric heights using either the HT2_0 hybrid geoid model (to get orthometric heights in the CGVD28 vertical reference frame), or by using the CGG2013 geoid model (to get heights in the CGVD2013 vertical reference frame). When working in the CGVD28 vertical reference frame this method disregards distortions in the CGVD28 levelling network and may not provide sufficient vertical accuracy for survey requirements.

When the user needs local heights relative to established vertical control, or is working over a large area it may be necessary to perform a vertical calibration. Similar to the horizontal calibration, a vertical calibration can be done by performing a localization using least four trusted benchmark monuments. These benchmarks should form a rectangle on the outside of the project area to the best extent possible (Henning, 2011a). With the estimated orthometric heights at a minimum of four vertical control points, the user can fit a tilted plane to the points and apply a correction to the estimated orthometric heights. Most commercial RTK software, as well as GPS-H from the Geodetic Survey Division of Natural Resources Canada can be used to calculate and apply this vertical calibration.

5. Summary and Conclusions

The goal of this document is to provide the users of both RTK and RTN surveys with a set of concise and easy to follow best practice guidelines. Some of the most important recommendations are summarized in this chapter. Appendix B also contains a checklist which can be used to verify all aspects of the survey.

Summary of Recommendations

- Be aware of what reference frame the RTK/RTN corrections are in.
- Verify RTK/RTN reference station availability and coordinate stability.
- If installing a base station establish coordinates using relative carrier phase GNSS or CSRS-PPP processing.
- Plan project to ensure RTK/RTN is suitable for project requirements (mixed survey methods might be most appropriate/efficient for project requirements).
- Ensure communication and RTK/RTN corrections are available throughout project area.
- Rover/Base Settings
  - Elevation Mask of 10-15 degrees
  - PDOP 2-3
  - Minimum number of tracked satellites set to six
  - Use mission planning software to determine optimal survey times
  - Use latest firmware recommended by the manufacturer
  - Save ellipsoidal heights in rover
  - Use only FIXED solutions
  - Set receiver QC value to slightly less than project accuracy requirement
- Check initialization as often as practical.
- Monitor the continuity, completeness, and latency of RTK/RTN incoming data.
- Avoid surveying when a weather front is passing through the survey area.
- Check the space weather forecast and use caution when working during increased ionospheric activity.
- Ensure GNSS is interoperable when mixing equipment from different manufacturers.
- Re-initialize after loss of communication and verify on a known or previously determined point.
- Monitor SNR values during survey.
- For important points do two separate time windowed observations of at least 1 minute with unique initializations.
- Verify accuracy of methods by checking into known points as often as practical.
- When possible, use two base stations (recording raw observations) when working with RTK. Alternately survey important points from both base stations.
- If required, perform a horizontal and vertical calibration after the survey.

The field of GNSS surveying is rapidly developing and this document was written with the intent that it will be updated as required. In the near future more navigation satellite systems and signals will be coming online (e.g. Galileo). As these new systems and signals become available in user equipment, there will be a requirement to adjust the recommendations accordingly.

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Appendix A – Summary of NAD83 (CSRS) in Canada

Evolution of NAD83 (CSRS) in Canada – Current as of June 2015

Version(epoch)	Frame	Adopted	Description
V0	Original	1986-1993	Horizontal adjustments
V1 (1988.0)	CSRS96	1996	Transformed from ITRF93
V2 (1997.0)	CSRS98=CSRS	1998	Transformed from ITRF96
V3 (1997.0)		2000	Transformed from ITRF97 (1st complete CBN)
V4 (2002.0)		2002	Transformed from ITRF2000
V5 (2006.0)		2009	Transformed from ITRF2005
V6 (2010.0)		2012	Transformed from ITRF2008

Summary of NAD83 (CSRS) Adoption in Canada – Current as of June 2015

Agency	Version	Comments
GSD	V6.0.0 (2010.0) on CACS/CBN	Mixed versions others
CHS	V5.0 (2006.0)	Moving to v6
BC	V4.0.0 (2002.0)	Vancouver Island Public Network v3.0 (1997.0) Moving to v6
AB	V4.0.0 (2002.0) on 1140 subset, v0 others	Moving to v6
SK	V2.0.0 (1997.0)	
MB	V2.0.0 (1997.0)	Moving to v3.0.1
ON	V6.0.0 (2010.0) on 8300 subset, v0 others	
QC	V2.0.0 (1997.0)	
NB	V2.0.0 (1997.0) on HPN	
PEI	V6.0.0 (2010.0) on ACS; v2.0.0 (1997.0) on HPN, NAD27 others	
NS	V6.0.0 (2010.0) on NSACS; v3.1 on HPN, ATS77 others	
NL	V6.0.0 (2010.0)	
Territories	V6.0.0 (2010.0) for SGB/NRCan surveys	Mixed versions others

Appendix B – Field Checklist

Item	✓ or n/a	Notes
General Planning		
Number of stations to be positioned		
Time available		
Number of rovers required		
Number of base stations required		
Rover occupation strategy		Loops, repeated occupations etc.
Search control agency records		Known stations in area
Get control description sheets		For locating stations
Use of multiple systems required?		GLONASS, GPS
Check satellite availability		
Check RTN availability		Is project within the "net"
Pre Field Equipment Checks		
All measuring hardware complete and operational		GPS equipment
Receiver firmware and software		Base & Rovers; Radios - up to date
All radio hardware complete and operational		Radio receiver, transmitter, antenna – check settings & communication between units
All accessories accounted for and checked		Tripods, bipods, poles, level bubbles, tribrachs, mounts, backpacks, tape measures
Batteries (GPS, Radios etc.)		Good condition and charged
Cables (GPS, Radios etc.)		All present and in good condition
Project data		Checked and uploaded to Base & Rovers
Project parameters input		Reference frame, map projection, geoid model
Set Max PDOP/elevation mask		Max PDOP (2-3); Elevation Mask (10-15deg)
Set Min # of satellites tracked		GPS only (6); GNSS (7-8)
Pre Field RTN Checks		
Contact RTN provider		Verify current updates to hardware & software, reference frame, base coordinates, planned station outages, and other system issues
Check operation		Ensure corrections can be received
Field Checks - Base Station Site Selection		
Identification and verification of control station		Check condition, markings, description, ties to reference marks
Sky visibility		Clear if possible and allowable
Check for multipath sources		Remove or note as appropriate

Security, accessibility, land owner permission		Secure site or supervision required? Permission and/or gate keys required? Drive, short/long walk, terrain
Place nail, monument etc.		If required for future use
Field Operations – Base		
GPS Antenna set up		Centered, levelled and connected
Batteries		Connected, sufficient charge for duration
Receiver operational and tracking		Check number of satellites tracked
Check Receiver settings		Project parameters, PDOP, elevation mask etc.
Radio antenna		Extended to max and connected
Radio		Connected to GPS and transmitting
Equipment secured		Against weather, animals, theft etc.
Field Operations – Rover		
Rover Antenna HI		Record Manually (metric and imperial)
Rover Antenna Type		Verify correct antenna type (or NULL)
Check receiver settings		PDOP, elevation mask, QC values
Record station # and approx. time of occupation		Manually in field book
Monitor QC reports from Rover		Ensure sufficient internal precision
Monitor Initialization time		Usually 1-2 minutes for fixed solution
Observe quality of radio link		
Monitor RTK age		2 second maximum
Monitor initialization status		Fixed Solution
Monitor weather		Avoid significant differences in weather between base and rover
Verification of Results		
Time Windowing		Minimum 1 minute for control and 5 seconds for topographic points
Occupy known points		Checks to known control within 3cm horizontal, 5cm vertical @ 95%
Re-occupy points using different base		Best for redundancy.
Re-occupy points using same base or RTN		Re-initialize every time, minimum 20 minute time separation, agreement within 3cm horizontal, 5cm vertical @ 95%
Check atmospheric conditions		Be aware of weather and solar activity

Appendix C – Questions To Ask Your RTN Service Provider

1. What reference frame and epoch are the RTN corrections with respect to? Are the reference station coordinates approved by the appropriate government authority?

2. What type of integrity monitoring is performed on the network stations? Where can I find a report of their coordinate stability?

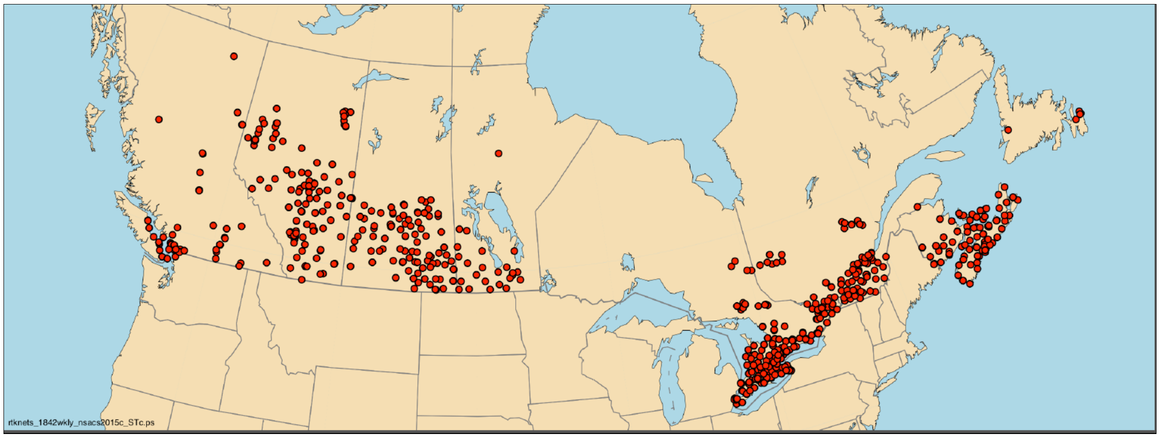
3. Where can I get a network map? Does my project area lie within the RTN?

4. Are there any recommended hardware or software updates for my equipment? Are there any interoperability issues with my equipment set?

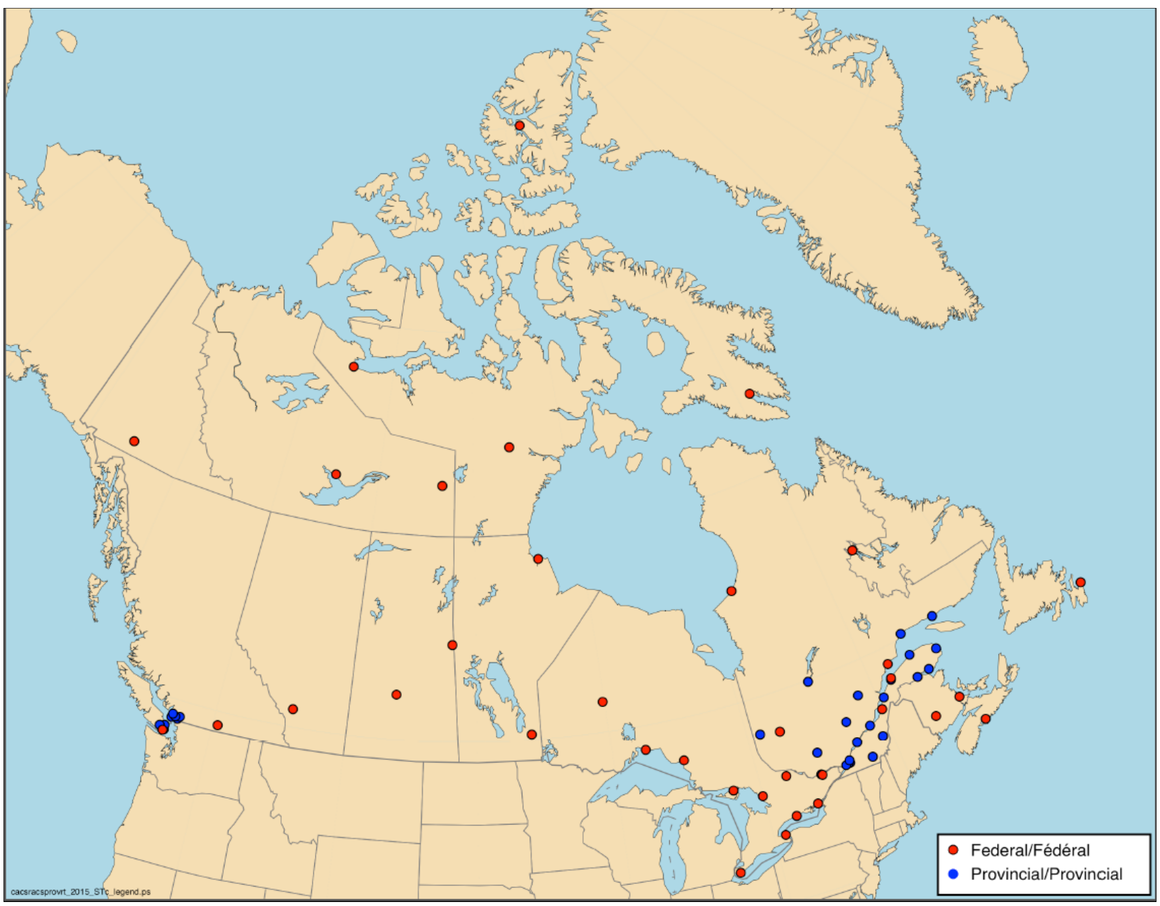
5. Are there any unique areas of outages or weak service within the RTN?

6. Where can I find real-time information on the service status including station outages during my survey?

Appendix D – RTN Coverage in Canada



Private real-time networks in Canada (July 2015)



Public real-time stations in Canada (July 2015)