Implementation of Real-Time Quality Control Procedures for Network RTK GNSS Positioning

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Key words: Real-Time, Quality Control, CORS Network, Mobile User, Network RTK.

SUMMARY

Real-time Global Navigation Satellite Systems (GNSS) positioning is becoming more and more accessible and reliable due to the rapid growth of Continuously Operating Reference Station (CORS) networks around the world and a new form of positioning known as Network Real Time Kinematic (NRTK). As a result, the number of users as well as the range of applications of GNSS has increased substantially. This growth has brought with it some interesting challenges one of which is to ensure that GNSS is performing at the required level of accuracy and precision. This has also placed an added responsibility to the suppliers of NRTK services to ensure that they can consistently satisfy the requirements of the users. At the moment there is no reliable system that can inform users as well as providers of NRTK services to the quality of positioning data.

This research is concerned with developing and implementing a robust, independent quality control system that will inform users in real-time of the quality, dependability and fitness-for-purpose of NRTK positioning results. This paper will describe the current state of development of the system and will present some preliminary results from a kinematic railway survey.

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1. INTRODUCTION

Current indicators of position quality for mobile users operating in the Network Real-Time Kinematic (NRTK) environment can be unreliable and at times fail to correctly convey the true accuracy and precision of the position solution. Such quality indicators fail to take into account the quality of the data provided by external sources, such as Continuously Operating Reference Station (CORS) networks, despite relying heavily upon this data for positioning. At the same time CORS network operators must also ensure that the quality of the data they provide is dependable and reliable and, in cases where the quality is degraded (for example due to an instantaneous spike in ionospheric disturbance), alert the users in a timely fashion.

This research is concerned with developing a Real-Time Quality Control (RTQC) system which will enable an independent assessment of the quality of NRTK positioning for mobile users as well CORS network operators in real-time and alert users of potential issues as they arise. The design of the system is shown in Figure 1. The system is comprised of three parts: RTQC CORS, RTQC Mobile and RTQC Premium. The system collects data from both the CORS network and mobile users and quality accesses it using RTQC CORS and RTQC Mobile modules respectively. Two separate modules are required due to the fact that quality assessment process differs for stationary and moving receivers.

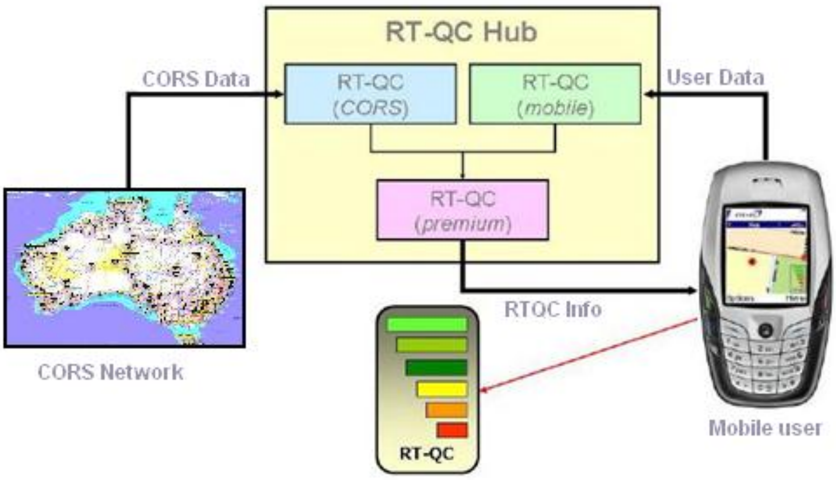

Figure 1. RTQC Setup

There are several features that make the RTQC system unique. One of them is that the quality control computations are based only on raw observations, which makes the system independent from manufacturer-specific algorithms and applications. Another aspect of RTQC is that the overabundance of quality indicators currently available is replaced with a single all-encompassing quality indicator. The derivation of this indicator is done in three steps and the process is shown in Figure 2. Firstly individual quality indicators (*q*)**,** are computed for each satellite/receiver range on an epoch-by-epoch basis. The derivation of *q* is outside the scope of this paper, but put simply, *q* represents the random noise in the carrier phase observations and as such it is in units of metres. Typically, the value for *q* will be in the order of a few millimetres.

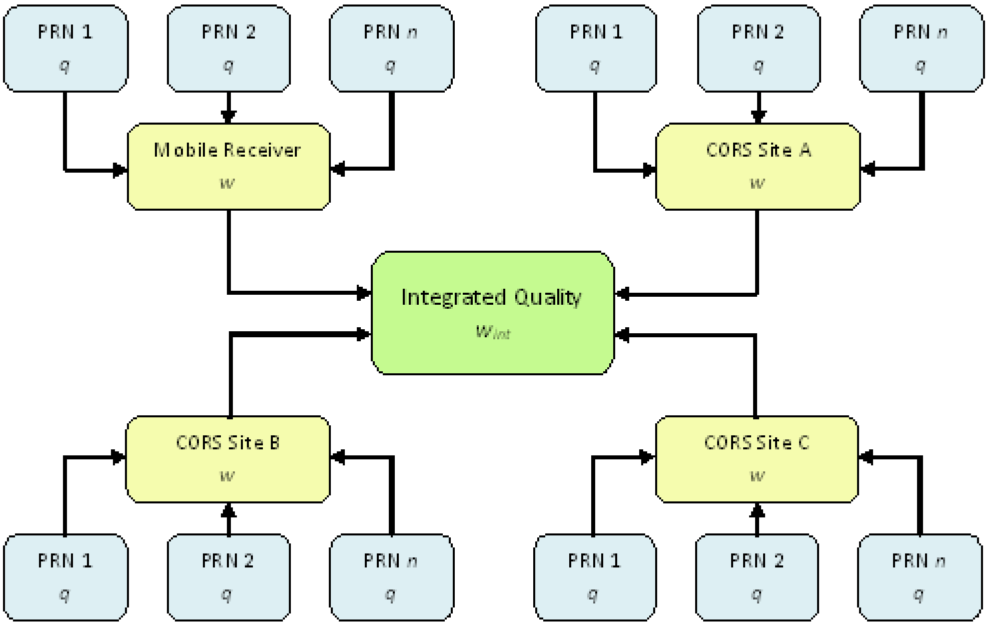

Figure 2. RTQC Quality Indicators

A single, receiver-based, quality indicator (*w*) is then derived from a combination of all available individual indicators (*q*) for each satellite being observed. This receiver-based indicator is unitless and is in fact a statistical ratio similar to the global test statistic used in least squares adjustments. For stationary receivers (eg. CORS receiver) this indicator is used to test the overall quality of the positioning data. For mobile users, an *integrated* quality indicator (w_{int}) is used, which takes into account the quality of the user's data as well as the quality of the reference stations upon which the user's positioning is based. For the derivation of *w* and w_{int} see Fuller *et al* (2010).

The integrated quality indicator for the mobile user is the information that is ultimately provided back to the user in real-time in the form of "signal strength" indicator, akin to those seen on mobile phones. A program runs in the background on the user's mobile device and the indicator is shown on the taskbar without interfering with the user's data collection software. This set up is simple, does not add any additional hardware to the user in the field and does not interfere with normal survey operations. The advantage is that the users have an independent check on the quality of positioning which takes into account the quality of CORS data on which the user's positioning is based, and as a result is more rigorous than the autonomous receiver QC indicator.

For a complete description of the RTQC system see Fuller *et al* (2007). This paper will concentrate specifically on RTQC Mobile which deals with quality control for mobile users. It will describe in detail the technical aspects of the system, including the choice of GNSS data standards and internet protocols to be used for data transfer and the configuration of receivers to enable them to perform RTQC procedures. The RTQC project is entering its final stages which involve, among other things, rigorous testing of the system. Until now, testing has concentrated on RTQC CORS with the software currently (September 2009) undergoing beta testing on various government and private CORS networks throughout Australia (Fuller *et al*, 2008). The testing of RTQC Mobile is just commencing and this paper will describe the first test that was carried out, which was a kinematic railway survey in suburban Sydney. It will also present some preliminary results on the performance and interpretation of a new independent quality indicator for mobile users.

2. RTQC MOBILE CONCEPT

2.1 General

One of the tasks of the RTQC system is to assess the quality of NRTK positioning for mobile users and to advise users of the quality of their positioning in real-time. Providing quality information for mobile users in a NRTK environment can be very demanding as the user's position can change rapidly, and positioning can be affected by various sources of error including multipath, signal obstructions, signal diffraction and interference from various sources.

A major difficulty faced by the research team in the development of RTQC was to make the system work seamlessly with the different hardware and software configurations employed by mobile users. In this context, it was obvious that a generic solution capable of operating independent of the mobile user's hardware/software combination, would be the preferred approach. As a result a simple web application was developed with the sole purpose of displaying the RTQC quality indicator. The advantage of this approach is that it can be used on practically all mobile devices with internet access and can be modified, maintained and updated without having to install software on the user's mobile device. Some issues had to be considered such as the standard compliance (content needs to be free of client based scripting or applets that may not be supported on all devices) and the amount of content to be displayed (Fuller *et al*, 2007). The last issue was particularly important as large amounts of content could slow down communications on bandwidth-limited devices. The volume of data in RTQC rovers is increased compared to normal NRTK rovers. Typically an NRTK rover will only have one communication channel used for receiving correction data from a CORS network. An RTQC-enabled rover will require three channels: the first to receive CORS network corrections, the second to send positioning information to the RTQC Hub and the third to receive the integrated quality indicator from the RTQC Premium module. This setup is illustrated in Figure 3.

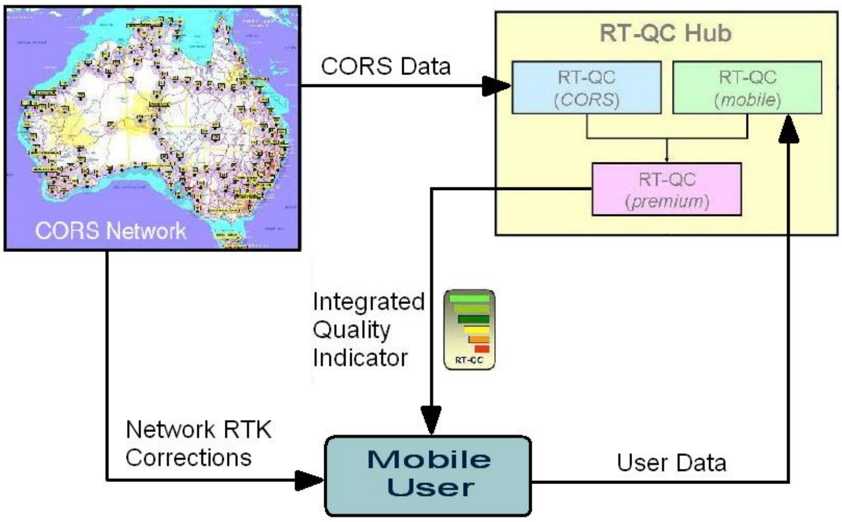

Figure 3. RTQC Mobile Setup

A number of considerations had to be taken into account when attempting to provide quality information to mobile users via the internet. These included the choice of GNSS data standard and also the choice of the internet transmission protocol to be used as a communications channel. As these are crucial to the success of the system, they will be discussed in more detail below.

2.2 GNSS Data Standards

The first issue that needed to be addressed was the choice of a GNSS data standard to use when streaming real-time data from the rover to the RTQC Hub. It was essential to get the right standard for the system to function correctly and efficiently. An inappropriate choice of standard could result in lack of information being received or slow down the communication channel. The standard also needed to contain all the raw messages required for the RTQC quality control computations.

Several standards exist for transmitting real-time GNSS data. Some of these are open, which means they are supported by various manufacturers and their specifications are publicly available. Others are manufacturer specific which means they are tailored to suit only one brand of receiver and are generally proprietary. Some of these will be discussed in more detail below.

One open standard that can be used for GNSS data transfer is the Real-Time International GNSS Service (RT-IGS) developed by the IGS Real-Time Working Group (RT-IGS, 2009). RT-IGS refers to both a GNSS standard and an internet transmission protocol. The RT-IGS standard consists of four messages: the station message (every 2 hours), observation message (every 1 second), ephemeris message (upon issue) and meteorological message (every 5 minutes). RT-IGS contains all the raw data messages needed for RTQC computations, however its implementation is limited to organisations that participate in the IGS Real-Time Working Group. Most major GNSS manufacturers do not support this standard.

RTCM is a standard created by the Radio Technical Commission for Maritime Services Special Committee 104 (RTCM SC-104) for transfer of GNSS data. There have been several versions of the standard which can be classified into RTCM Version 2.x and RTCM Version 3.x. Version 2.x had several issues with efficiency, with the main one being the 30 bit parity scheme which was awkward to handle, wasteful of bandwidth and degraded the integrity of the message. Version 3.0 was released in 2004 to overcome this weakness and concentrated primarily on messages designed to support RTK operations. Version 3.0 included messages for GPS and GLONASS code and carrier observables, antenna parameters and ancillary system parameters. The latest version of the standard, RTCM Version 3.1, also incorporated GPS Network Corrections (RTCM, 2006), which made it an ideal option to use with RTQC. Thus RTCM Version 3.x (hereafter RTCM3) was chosen over RT-IGS as the preferred standard for RTQC data transfer due to its wide usage and support by GNSS manufacturers. The research team have been provided with a registered RTCM message type (RTCM 4082 message) specifically for the purpose of transferring quality information to mobile users.

As well as open standards such as RTCM and RT-IGS, most GNSS manufacturers have designed their own proprietary data transmission formats, and some have more than one. Table 1 presents some known standards from the major GNSS manufacturers.

Table 1. Proprietary GNSS data transmission standards.

Manufacturer	**Standard**
Leica	LB2, 4G
Trimble	CMR/CMR+/CMRx, RT17/RT27
Novatel (and Sokkia)	RANGE
Topcon	TPS
Javad	JPS
Magellan	MBEN/PBEN, DBEN, ATOM™
AOA	ConanBinary, TurboBinary
JPL	SOC

These standards vary in the type of information they provide and are generally customised to suit the individual manufacturer's hardware requirements. They are generally in binary form and hence are efficient in bandwidth usage. Being proprietary, these standards are not normally available for general use.

2.3 Internet Transmission Protocols

The rise of CORS networks has introduced additional challenges in streaming real-time differential correction data. Previously, corrections were transmitted via radio link, DGPS beacon or a communications satellite, but the advent of high speed mobile internet has introduced an additional and often superior method of accessing data in real time. Two new internet transmission protocols have been developed as a result – NTRIP and RT-IGS.

As mentioned above, RT-IGS, as well as being a GNSS standard, is also a transmission protocol which is used to transmit GNSS data over the internet. RT-IGS is transmitted using the UDP (User Datagram Protocol) transport layer. The advantage of using UDP is that it provides a fast connection, but the disadvantage is that it does not guarantee delivery, nor does it maintain message order. Therefore it is the responsibility of the recipient of the messages to validate the quality and quantity of the delivered data (Muellerschoen and Caissy, 2004).

Networked Transfer of RTCM via Internet Protocol (NTRIP) is also an application level protocol designed to stream differential correction data over the internet (BKG, 2005). NTRIP is a generic, non-proprietary protocol based on Hypertext Transfer Protocol HTTP/1.1 and uses TCP (Transmission Control Protocol) as the transport layer. Contrary to its name, it can disseminate any kind of differential data over the internet, not just RTCM. The advantage of using TCP as a transport layer (in contrast to UDP) is that it establishes a reliable connection between two IP addresses. If a loss of connection occurs, it will be automatically recognized by the TCP-sockets and this occurrence can be used to trigger software events such as an automated reconnection. NTRIP has gained wide popularity as a protocol of choice when it comes to disseminating GNSS data over the internet. Many new GNSS receivers now come with a built-in NTRIP feature enabled. Because of its almost universal acceptance, NTRIP has been adopted as the standard protocol to be used by RTQC. The concern with RT-IGS was the use of UDP protocol, which does not guarantee reliability. NTRIP on the other hand requires acknowledgements of packet arrivals and re-transmission of lost packets, and hence guarantees consistency and reliability (Muellerschoen and Caissy, 2004). For a comprehensive discussion on relative merits of NTRIP and RT-IGS see Yan *et al* (2009).

3. RTQC MOBILE DEVELOPMENT

3.1 Receiver Set Up

RTQC CORS has worked well based on RTCM3 as the data standard and NTRIP as the transmission protocol. However, problems were encountered with implementing the RTQC Mobile module since it has been discovered that most GNSS receivers do not stream RTCM3 data when operating in rover mode. This option is normally only available if the receiver is set up as a reference station. Hence an alternative way had to be found to transmit mobile user data to the RTQC Hub. Two solutions were considered. The first was to incorporate proprietary formats, the second was to use mobile receivers in the so-called “moving base” mode.

Enabling RTQC to deal with proprietary data formats was not a preferred path for the development team because of the difficulty of gaining access to the required format specifications and the complexity of working with these non-standard formats. To date, agreements have been reached with Leica Geosystems and Topcon to use the LB2 and TPS formats respectively. Novatel's RANGE and Javad's JPS formats are publicly available for implementation. The LB2 decoding capability has been added to RTQC and tested successfully in a real-time environment. Software to decode the Topcon, Javad and Novatel (and hence Sokkia) proprietary formats is currently being developed. Discussions are being held with other GNSS manufacturers (eg. Trimble, Magellan) about adopting RTQC procedures with their receivers.

Another way to stream positioning data from the rover receiver to the RTQC Hub is to use a moving base configuration. Some manufacturers have GNSS receivers capable of moving base operation. A moving base acts exactly as a static base with the exception that the receiver's position is allowed to change. This feature has been designed mainly to support marine applications. The moving base mode has proved a convenient way to test the RTQC system because it allows two essential things: real-time, dynamic positioning within a CORS network and the transfer of raw measurement data to the RTQC Hub in RTCM3 mode via NTRIP.

The first two receivers that were configured for testing the real-time operation of RTQC Mobile were a Novatel DL-V3 receiver being used in moving base mode and a Leica System 1200 receiver in rover mode streaming the proprietary LB2 format.

3.1.1 Novatel Moving Base Set Up

Figure 4 depicts the moving base configuration which has been implemented and successfully tested with RTQC. The diagram shows a Novatel DL-V3 receiver running in moving base mode and a survey controller with a mobile internet connection being used as a mobile device. The CORS network corrections are being sent to the mobile device and passed to the GNSS receiver via serial or Bluetooth connection. The receiver then calculates its position using NRTK algorithms and sends the observation data in RTCM3 format to the survey controller (again via serial or Bluetooth) from where it is sent to the RTQC Hub. RTQC then performs its quality assessment computations and sends the integrated quality indicator back to the user in real-time.

The moving base approach can be used for kinematic applications where the receiver is collecting data from a moving platform such as a car, train or ship, however this method is not suited to RTK surveying. The reason for that is that in a RTK survey the user needs to run some sort of data collection software on a mobile device which needs to be connected to a 'rover' receiver. Another disadvantage of the moving base configuration is that it is quite a specialised application and as such there are only a limited number of GNSS receivers capable of using this approach.

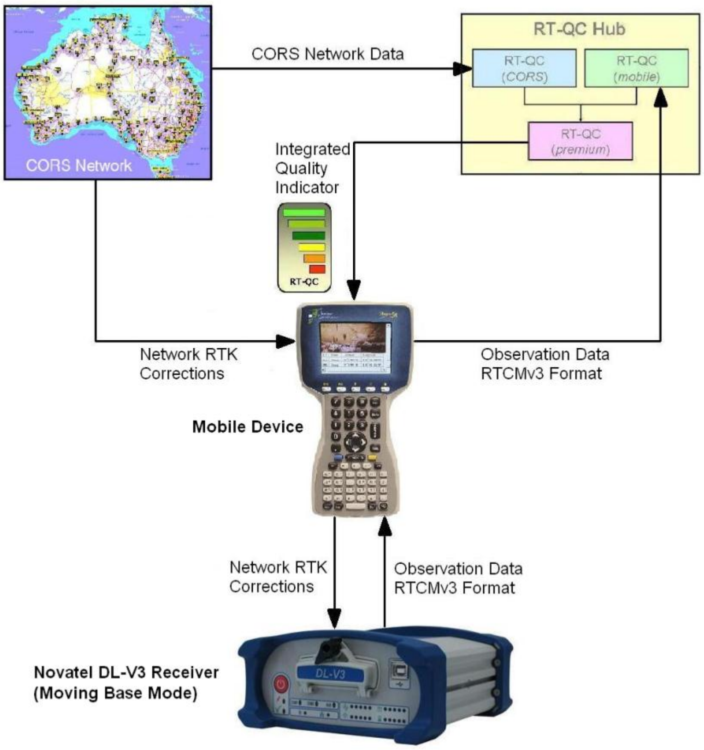

Figure 4. Novatel Moving Base Set Up.

3.1.2 Leica LB2 Rover Set Up

Figure 5 shows the Leica configuration, with the Leica 1200 receiver being used in rover mode. It can be observed that this setup differs from the Novatel moving base configuration in that the CORS network corrections are being sent directly to the GNSS receiver which has a modem attached to it. From there the observation data in LB2 format is sent to the mobile device and then to the RTQC Hub. The integrated quality indicator is then computed and sent back to the user in real-time. This setup is superior from the RTQC perspective as the receiver is in the rover mode and hence can be used for RTK surveying as well as any other form of dynamic positioning task.

3.2 Kinematic GNSS Railway Survey

After these two configurations for RTQC mobile were made operational, they were tested on a kinematic railway survey in Sydney. Project partner Geomatic Technologies has a contract to map 50 kilometres of railway track in Sydney on a regular basis to check for damage to the tracks. These surveys are conducted using a single train cart equipped with a GNSS receiver and digital cameras. These repeated rail track surveys provided an ideal real-life “laboratory” for RTQC Mobile testing for several reasons:

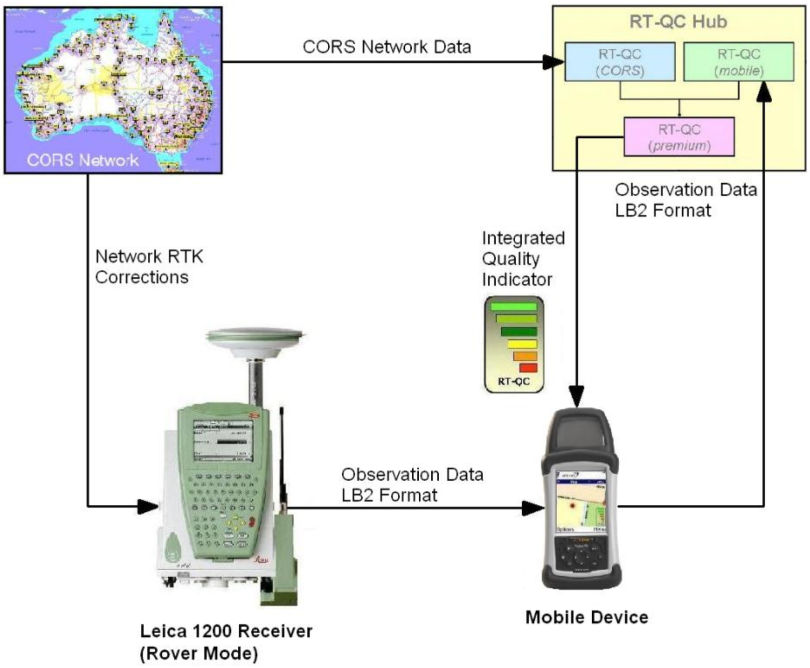

Figure 5. Leica Rover Set Up.

- The availability of an existing CORS network
- The dynamic nature of the surveys
- The challenging environment (multipath and obstructions)
- The fact that the surveys are repeated on a regular basis

The goal of the railway test was two-fold. Firstly, to prove that the concept of RTQC Mobile is indeed achievable in a real-time, highly dynamic environment. Secondly, to assess the performance of the new RTQC quality indicator to see whether it can provide a reliable means of alerting the user when the positioning quality is poor.

It was decided to test both configurations described above on the train survey so that the relative merits of the RTCM3 (Novatel) and LB2 (Leica) formats could be assessed. Both receivers were connected to a single Leica AX1202GG antenna via a signal splitter and set up as per the configurations shown in Figures 4 and 5 respectively. The only difference was that instead of using a separate mobile device for each receiver, a single laptop computer was used. The laptop provided a wireless internet connection between the receivers and the RTQC Hub (running at the University of Melbourne) in much the same way as a survey controller or mobile phone would be used in a more conventional setting.

The route of the survey was from Sydney's Central station to Sutherland station 25 kilometres to the south-west and back to Central station. The CORS network used for the experiment was the Sydnet network (Sydnet, 2009) maintained by the Department of Lands, NSW. Sydnet consists of 18 stations available for both real-time and post-processed use. Unfortunately, a NRTK solution was not available at the time of surveys. However for the purposes of this experiment, a NRTK solution was provided by the School of Surveying and Spatial Information Systems of the University of New South Wales (UNSW) using three stations (Chippendale, Waterfall and Villawood) and the Leica GNSS Spider software (Leica Spider, 2009). The route of the survey and the CORS network stations are shown in Figure 6.

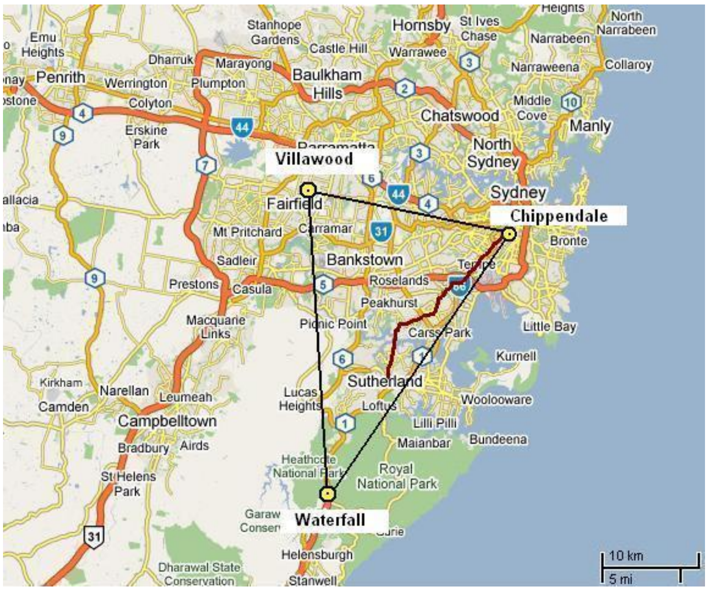

Figure 6. Train route and Sydnet CORS.

4. RESULTS

As stated, the first objective of the experiment was to test the setup of the system to prove that the concept of RTQC Mobile was achievable in real-time. To this end the testing was completely successful. Both receivers were capable of receiving corrections from the CORS network, sending their positional information to the RTQC Hub and receiving quality information from RTQC in real-time. Additionally this was happening in a highly kinematic environment with the train running at speeds of up to 80 kilometres per hour. The use of RTCM3 and LB2 formats had no significant impact on the performance of the system.

The second objective of the survey was to evaluate the performance of the RTQC quality indicators to determine whether they provided a meaningful indication of the mobile user's positioning quality and whether they were able to reliably detect and alert the user to problematic data. Testing the quality indicators on real world data collected in a difficult environment would allow the research team to acquire experience in the interpretation and analysis of the quality indicators and further the understanding of their behaviour. In particular, the rail track experiment provided the first opportunity to examine the performance of the integrated quality indicator in a real world setting, as the necessary equipment and systems were not available previously.

As discussed earlier, the integrated quality indicator combines receiver-based quality indicators from the CORS sites and mobile receiver to provide an overall measure of the mobile user's positioning quality. The results presented below begin with a discussion and analysis of the individual (CORS and mobile user) quality indicators before moving on to the integrated quality indicator. For clarity, only two satellites (SV8 and SV25) are discussed below. These satellites were chosen as they represent typical satellites in the sense that they exhibited similar trends to the other satellites, were neither high nor low in elevation, and were available for the duration of both surveys.

Figures 7 and 8 show the individual quality indicators for SV8 and SV25 during two identical surveys conducted on the 4th March 2009 (Figure 7) and the 1st April 2009 (Figure 8). Each figure displays the quality indicator for SV8 at the Chippendale CORS site and SV8 and SV25 at the mobile receiver (offset by 0.3m and -0.3m respectively to improve readability). It is immediately apparent from Figures 7 and 8 that the quality indicator for the CORS receiver is significantly smaller in magnitude and less volatile in nature than those for the mobile receiver. In contrast to the CORS receiver, the quality indicators for the mobile receiver are larger and exhibit greater variability, apart from a number of short periods (coinciding with the train being stationary) where their magnitudes are small and their behaviour stable. Further evidence of these trends can be seen in Tables 2 and 3, which detail the statistical properties of the quality indicators for SV8 and SV25 at the CORS and mobile receivers.

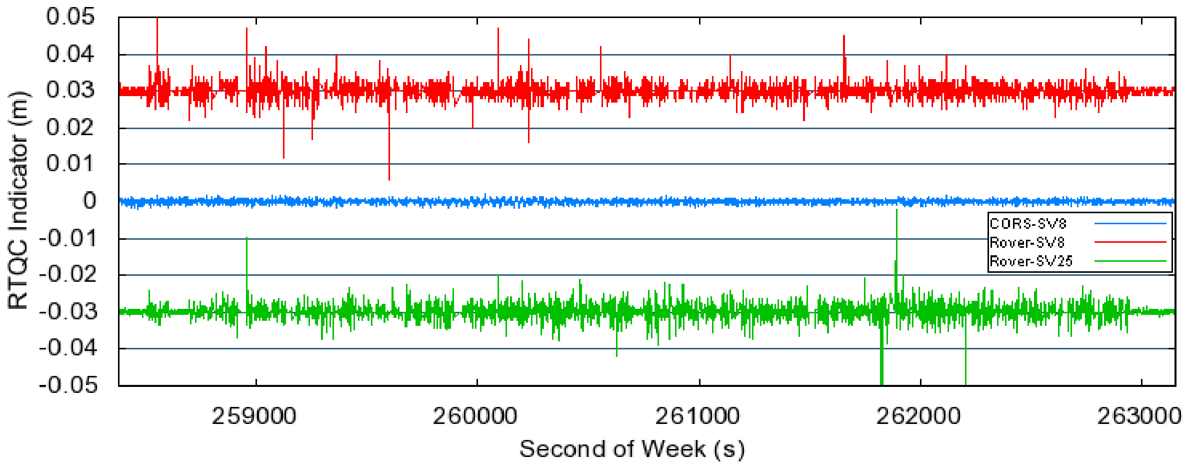

Figure 7. Individual RTQC Indicators during railway survey on 4th March 2009.

Table 2. Statistics of RTQC Indicators during railway survey on 4th March 2009.

	CORS		**ROVER**			
			Stationary		**Moving**	
	Mean (mm)	*Std Dev (mm)*	*Mean (mm)*	*Std Dev (mm)*	*Mean (mm)*	*Std Dev (mm)*
SV8	0.0	0.5	-0.1	0.9	0.0	2.2
SV25	0.1	0.5	0.1	0.7	0.1	2.4

The evidence in Tables 2 and 3 and Figures 6 and 7 confirms a basic property of the individual RTQC quality indicator, namely, that it describes the noise of the observations from epoch to epoch. For the case of a CORS receiver, operating in a "clean" environment, the systematic errors present under normal conditions vary in a predictable manner over time leading to optimum observing conditions and therefore low observational noise. On the other hand, a mobile user (in this case a train travelling at 80 kilometres per hour) experiences variable (often difficult) conditions where the systematic errors affecting the measurement process vary less predictably, resulting in noisier data. The behaviour of the quality indicator for the CORS and mobile receivers shown in Tables 2 and 3 and Figures 7 and 8 confirm this interpretation, as does the improved quality indicator for the mobile receiver whilst stationary. Without a constantly varying environment the magnitude and variability of the mobile user's quality indicator resembles that of the CORS receiver, albeit with an increased standard deviation (Tables 2 and 3). This is not an unexpected result considering the shorter observational span for the stationary components of the mobile receiver and the fact that, even when stationary, the observing environment would likely not be as clean as that for the CORS receiver.

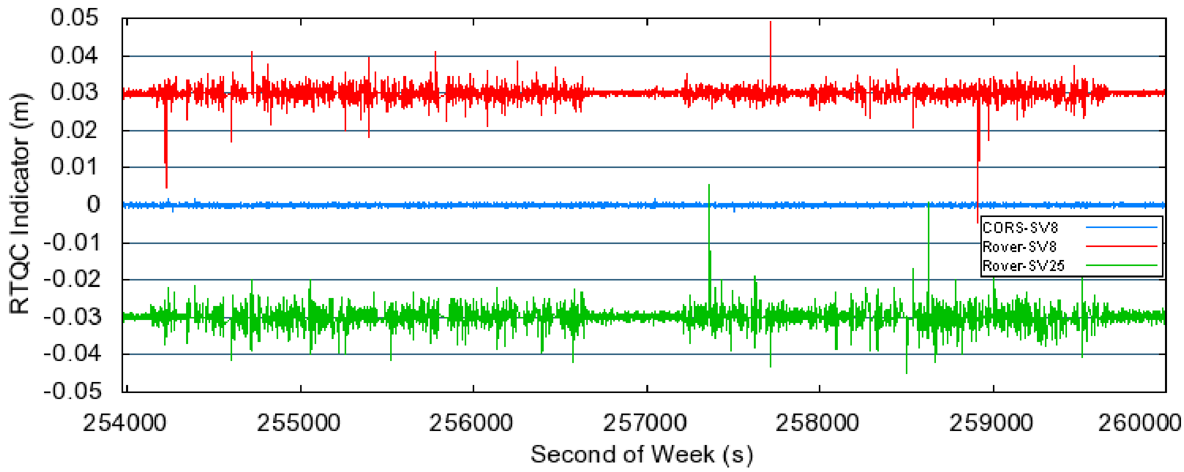

Figure 8. Individual RTQC Indicators during railway survey on 1st April 2009.

Table 3. Statistics of RTQC Indicators during railway survey on 4th March 2009.

	CORS		**ROVER**			
			Stationary		**Moving**	
	Mean (mm)	*Std Dev (mm)*	*Mean (mm)*	*Std Dev (mm)*	*Mean (mm)*	*Std Dev (mm)*
SV8	0.0	0.4	0.0	0.6	-0.1	2.0
SV25	0.0	0.5	0.2	1.1	0.1	2.7

No existing coordinate information (ground truth) was available for the railway track to provide a basis for further comparison of the real-time solutions. As an alternative, three-dimensional offsets between the two positioning solutions were computed to determine the location and magnitude of any significant coordinate difference. After analysing these differences against the spikes in the individual quality indicators, it was found that the major spikes occurred when one or both of the positioning solutions was a code-only solution. These low accuracy solutions prevented any further meaningful analysis of the positioning quality. However, the analysis of the quality indicator spikes did reveal the fact that these spikes frequently occur after data gaps, leading to the conclusion that, upon the initial re-acquisition of a satellite, a higher level of noise is often present in the observations.

The next stage of the analysis involved an examination of the quality indicators at epochs when initialisation was lost. The objective was to determine whether the quality indicators could warn of a potential problem as it occurred in real-time. For this purpose, data from the Leica receiver was post-processed using the Leica Geo Office software (Leica Geo Office, 2009) and the epochs when the solution changed from a phase-fixed to a code-only solution were identified. At the same time, the individual quality indicators were analysed for the presence of outliers at the identified epochs. For this purpose, a running mean and standard deviation were calculated from the previous 30 epochs. The quality indicator for the current epoch was compared to the running mean for each satellite. If the difference between the two was greater than three times the 30-epoch standard deviation, the present epoch was flagged as an outlier (see Table 4). To provide a benchmark against which to assess the number of outliers detected, the same method of statistical testing was also carried out on all epochs in which a phase-fixed solution was available.

Table 4. Outlier Detection Summary

Survey	Epoch Type	Num Epochs	Num Outliers	Percentage
1	Loss Initial Epoch	62	21	33.8%
1	All Phase Fixed Epochs	3472	821	23.6%
2	Loss Initial Epoch	43	14	32.6%
2	All Phase Fixed Epochs	2488	577	23.2%

From Table 4 it can be seen that 23% of normal epochs recorded an outlier on at least one of the satellites being observed. This is not unusual and has no real effect on the positioning solution. During the epochs at which initialisation was lost this number increased to 33%. Whilst this represents a 50% increase over a normal epoch, it was expected that this number would be much higher which led to the conclusion that the outlier testing was not discriminating enough. A closer examination of these epochs revealed that the standard deviations at the rover where 3-4 times higher compared to those observed at a CORS site which would unduly influence the outlier testing. In future the testing will be modified to include a longer moving window (used for calculating mean and standard deviation) and a direct comparison against a CORS site to produce more realistic results. These results also highlight the need for an integrated indicator that is comprised of CORS and mobile user data.

In RTQC, individual quality indicators are aggregated to form a receiver-based indicator for a single receiver (CORS or mobile user). An integrated quality indicator is then formed by combining receiver-based indicators from the mobile user and the CORS sites upon which the user's positioning is based. The contribution from the CORS sites helps to smooth the more unpredictable mobile user data without diminishing the ability of the integrated quality indicator to detect poor quality data (Fuller *et al*, 2010).

An analysis similar to individual indicators was carried out on the integrated indicator. During the first survey, 25 epochs were flagged as outliers by the integrated indicator. These outliers were analysed one by one and it was found that 15 of these epochs had either no positioning solution or code positioning solution and the remaining 10 had a phase fixed solution. Phase fixed epochs were examined more closely and compared to the single-differenced L1 and L2 residuals in the Leica Geo Office software. It was found that in 8 out of 10 epochs even though the solution was deemed phase fixed there were large L1 and/or L2 residuals present. One such example is shown in Figure 9 where it can be clearly seen that a spike in RTQC integrated indicator corresponds directly to the spikes in L1 phase residuals. This albeit preliminary analysis nevertheless highlights the worth of RTQC integrated indicator in real-time quality assessment process. More testing is required to get a better understating of its properties and fully assess its potential.

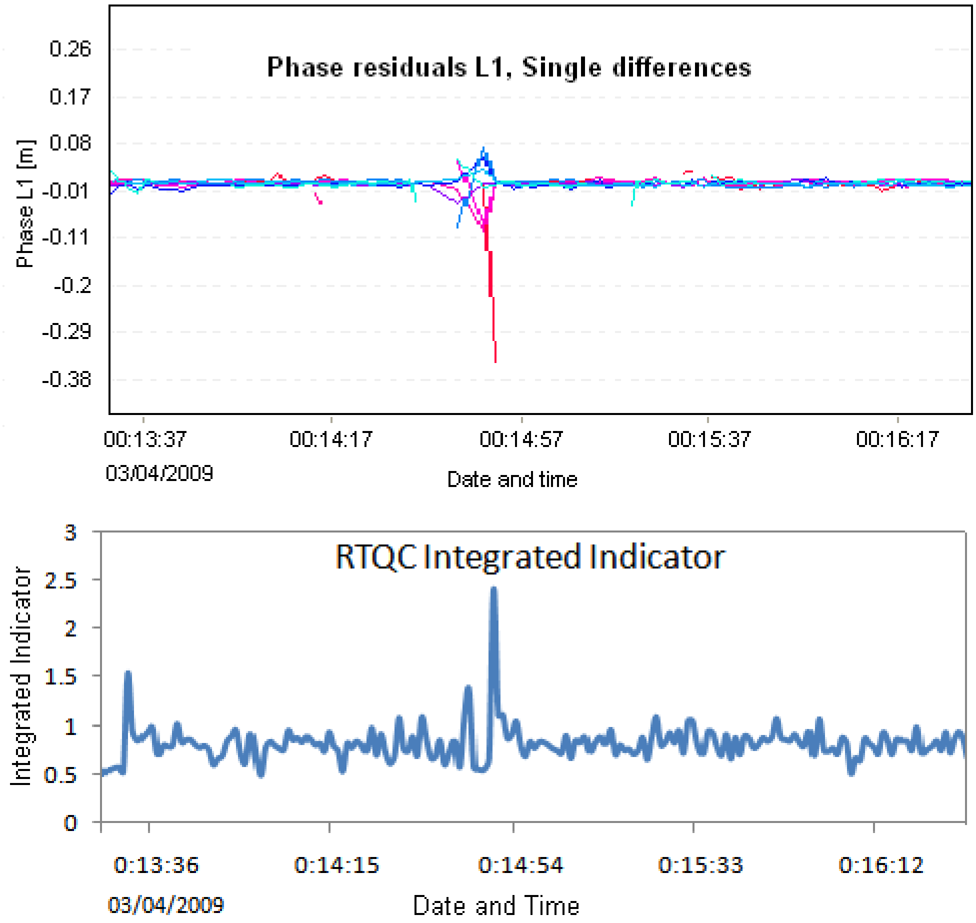

Figure 9. L1 Phase residuals and RTQC Integrated Indicator

CONCLUSION

The main goal of RTQC system is to provide quality control information for CORS network operators and mobile users performing NRTK positioning. This paper has described how RTQC system works for the mobile users. The setup of the system was presented including the choice of GNSS data standard and internet transmission protocol. Two methods for implementing RTQC procedures for mobile users were presented, using either proprietary formats or running the receiver in moving base mode. The associated advantages and disadvantages of each method were discussed. To date Leica and Novatel receivers have been configured to adopt the RTQC procedures. In the immediate future receivers from other manufacturers will also be configured and tested with the RTQC procedures.

Results of the kinematic railway survey were presented showing the ability of RTQC to deal with problematic data. It was shown from an analysis of two satellites that individual quality indicators were capable of describing the noise in carrier phase observations. In the absence of ground truth coordinates, comparison was not possible so epochs when the solution changed from phase fixed to code were analysed for the presence of outliers and it was found that the number of outliers was increased by 50% and that at other times large standard deviations were present which indicated noisy data, but did not flag measurements outliers. Finally brief analysis of an integrated indicator was given where it was shown that a significant number of measurements cast as outliers corresponded to either no positioning solution, code positioning solution or phase fixed solution with large residuals. Although these results are preliminary, they highlight the potential of RTQC indicators to be used in real-time quality assessment process. More tests will need to be carried out in different NRTK environments, especially in challenging areas where GNSS had known to be problematic (such as areas with interference) to fully understand the capabilities of the indicator.

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