University of Southern Queensland

Faculty of Engineering and Surveying

Calculation and Comparison of the Noise and Latency of RTK Observations using Radio Link and NTRIP

A dissertation submitted by

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ABSTRACT

In 2004, the application known as Networked Transport of RTCM via Internet Protocol (NTRIP) was developed to transmit Global Navigation Satellite System (GNSS) corrections for the purpose of performing Real Time Kinematic (RTK) surveys. NTRIP utilises the Internet Protocol (IP) thus eliminating line of sight problems associated with Radio Link caused by obstructions such as buildings and mountains.

Early use of NTRIP indicated that latency (time lag) of correction data was a problem as well as the positional uncertainty with respect to setting out points. Radio Link data (the conventional method of data transmission for RTK) has provided quality data for Global Positioning System (GPS) surveys for many years and provides the benchmark for a series of tests on NTRIP data. These tests will measure the noise and latency of NTRIP and Radio Link data.

Testing noise involved taking thirty static measurements to assess the horizontal precision of the data which can be directly related to signal noise. Testing latency involved driving a vehicle at a constant speed past a specific starting point. As the vehicle passed the starting point the measure button was pressed and a point was stored some distance past the starting point. This distance from the starting point to the stored point reflects latency in the signal.

The results found that signal noise has minimal affect on NTRIP data and the IP path in which the data is transmitted, thus horizontal precisions easily meet survey standards at the range of nine kilometres. The results from the driving test have demonstrated that latency of GNSS corrections using NTRIP have improved from early experiments carried out and are now in line with the latency times of Radio Link data.

The benefits of these findings will allow the surveying industry to use NTRIP with confidence knowing that latency times are minimal and that horizontal precisions meet survey standards and at nine kilometres are equal to that of Radio Link.

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Limitations of Use

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Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Table of Contents

List of Tables

List of Figures

1.0 Introduction

1.1 *Problem Statement*

Traditional Real Time Kinematic (RTK) surveys utilise radio link communication to distribute Global Navigation Satellite System (GNSS) correctional data between the Base receiver and a Roving receiver. The problem with this system is signal obstructions from features such as buildings and mountains. The next generation system known as Networked Transport of RTCM via Internet Protocol (NTRIP) is a method of transmitting GNSS correctional data through an internet connection from a Base receiver or a Continuously Operating Reference Station (CORS) to a Roving receiver for RTK surveying applications. A CORS is a type of permanently fixed Base receiver which constantly collects GNSS data and transmits GNSS corrections for RTK surveys.

The problem with the NTRIP method is that there is a time delay from when the correctional data is transmitted from the Base receiver and when it arrives at the Roving receiver as discovered by a work colleague at RPS Group two years ago. Subsequently, the quality of the data is of sub standard due to this delay and would therefore be of less use for surveying tasks that require high precisions. This is a problem for the surveying industry when standards are attempting to be upheld and precisions are of utmost importance.

NTRIP transmitted data has '*sufficient positioning precision if correction data is not older than a few seconds. Latencies in the order of three to four seconds are typical for RTK applications*' (Weber, Dettmering, Gebhard, 2004 pp2, 4). The above statement identifies that correction data does suffer a latency period while using the NTRIP application, however is not precisely known nor has it been tested against a benchmark method such as Radio Link.

1.2 *Research Aim and Objectives*

The aim of this dissertation is to calculate the noise and latency of GNSS correctional data transmitted from a Continuously Operating Reference Station (CORS) to a Roving receiver through an internet connection and compares them with the traditional method of radio link transmission.

The objectives of this study are :

- To determine whether internet transmitted correctional data is affected by noise or latency and calculate these affects
- To compare the noise and latency of internet transmitted correctional data against data transmitted using conventional radio link
- To provide recommendations to the surveying industry for possible future study in the area of internet data transmission and best practices using the internet as a medium for transmitting correctional data

Achieving these objectives will enable conclusions to be made regarding the effect noise and latency has on the NTRIP method of data transmission.

1.3 *Background and Justification*

Due to the increased capacity of the internet and mobile phone networks, Real Time Kinematic (RTK) surveying has undergone some improvements with respect to the transmission of Global Navigation Satellite System (GNSS) correctional data. The conventional method of transmitting correctional data is through radio link communication. The latest development for the transmission of GNSS correctional data to the end user is through an application known as Networked Transport of RTCM via Internet Protocol (NTRIP).

The conventional radio link method is highly functional and provides very precise results to the standard of +/- 10mm + 1 part per million with RTK surveying (Trimble 2009); however the limiting factor is line of sight which is required for radio communication. Line of sight can be obscured by features such as thick vegetation, hills and buildings. The NTRIP development has revolutionised RTK surveying as it eliminates these line of sight problems as GNSS correctional data is transmitted through the internet. While the internet is an emerging option for the transmission of GNSS correction data, it also has its own limitations such as internet connection problems associated with the geographic position of some surveying task.

The statement in section **1.1** by Weber et al (2004), "*latencies in the order of three to four seconds are typical for RTK applications*" suggest that NTRIP data received at the user end is affected by a period of latency in the order of three of four seconds. Latency can be defined as something that exists but is not yet developed after a period of time (Oxford Online 2011). Gibbings and O'Dempsey, (2005) defined latency in their study '*Using GPS Asset Mapping Software for Hydrographic Measurements in Still Water', as* a time lag between when a GPS position is measured and when it is recorded. According to Weber et al (2004) latency is the result of transmitting correctional data through the internet which involves sharing the resources of an Internet Service Provider (ISP); hence the available bandwidth to send data is uncontrollable.

Weber et al (2004) conducted tests on the latency and positional accuracy using the NTRIP protocol; although a direct comparison of NTRIP and radio link was not carried out, it was found that NTRIP data was subject to a latency period. The inclusion of radio link data in the testing programme will provide a benchmark against which the NTRIP data can be subjectively compared, with respect to data quality and timings.

Evidence provided in the articles by Weber et al (2004) and Chen, Li and Weber (2004) suggest that there is definitely a latency period of three to four seconds when utilising the NTRIP protocol. Despite this, Weber et al (2004) also concludes that achievable accuracies using NTRIP are not downgraded, however this was not proven and does not state what the benchmark accuracy was in that particular article.

Anecdotal evidence from a fellow work colleague in 2009 from RPS Group on the Sunshine Coast, whom has experience using the RTK surveying technique, that GNSS correctional data is subject to definite variations in the quality of data received at the Roving receiver. This discovery was in line with results founded by Weber et al (2004) and Chen et al (2004) that correctional data transmitted through the internet, when received by the end user is delayed and lacks positional certainty; whereas correctional data transmitted using radio link is received instantaneously and is definite in its positional certainty.

Radio link has been the standard form of communication of GNSS corrections for RTK surveying and provides high precision results which meet the survey standards set by the Inter-Governmental Committee on Surveying and Mapping (ICSM) which is 10mm +/-2ppm (parts per million); it is therefore necessary to test and compare the noise and latency of GNSS correctional data and the subsequent precisions for both methods of transmission. This research is warranted because the purpose of the RTK surveying technique is to provide 'real time' corrections of high precision and accuracy and if NTRIP data does not provide this then it requires documentation.

1.4 *Scope and Limitations of Research*

Prior to undertaking this study, it was critical to fully understand the concept of NTRIP and how it works. Resources such as articles from the founders of NTRIP, textbooks and web articles from industry leaders have been used to gather information. The knowledge gained will permit further investigation into the effectiveness of the NTRIP application and the possible items that may impact the ability to meet survey accuracy requirements.

A review of literature will provide information on origins and development of NTRIP and provide information regarding previous testing and results.

The dissertation will specifically analyse and assess GNSS correctional data measured using the transmission methods of radio link and the internet. A statistical analysis will be carried out to enable conclusions to be made regarding the affect that noise and latency have GNSS correctional data transmitted using NTRIP.

This dissertation will exclude investigations of how GNSS corrections are actually transmitted through an internet connection and how other internet uses and bandwidth affect the quality of correctional data transmitted.

1.5 *Summary*

This dissertation aims to calculate the noise and latency of GNSS correctional data transmitted from a Continuously Operating Reference Station (CORS) to a Roving receiver through an internet connection compared with the traditional method of radio link transmission. The objectives set out will provide a logical programme structure that will ensure a comprehensive dissertation is carried out.

The research is expected to uncover new information relating to GNSS data and specifically the NTRIP application. Given that NTRIP is a relatively new technology, research will begin in a broad sense covering the entire Global Navigation Satellite System and then narrow in to more precise information.

The review of literature for this research will assist in the identification of detailed information relating to NTRIP, the origins of the concept, how it works, the equipment used and the benefits. Most importantly, the literature review will enable me to identify operational or functionality issues that may have been documented by reputable sources. For example, any testing that has been performed and documented will highlight potential issues that may require further investigation.

A testing programme will be constructed from the findings of the literature review. The findings and outcomes from the testing programme will further improve the knowledge of the industry and will contribute to enhancements with the NTRIP application.

2.0 Literature Review

2.1 *Introduction*

This chapter will outline the basics of RTK surveying and the specific differences in the two techniques for transmitting GNSS correctional data, radio link transmission and the internet. This chapter will provide a review of literature that will outline information relating to the origins and the reasons that have attributed to the development of NTRIP.

The review of literature will establish what previous testing has been performed on NTRIP, in particular the affect of noise and latency. Critically analysing previous test data will provide information that may assist with the research methodology and outcomes of this dissertation.

2.2 *Real Time Kinematic Surveying Basics*

Real Time Kinematic (RTK) surveys can only be performed when two Global Navigation Satellite System (GNSS) receivers have visual sight of the same satellites. When this is achieved relative positioning can be performed, where the differences between the stations are measured and a correction amount is computed.

RTK surveying involves positioning a Base receiver a known coordinated point and a Rover receiver positioned at the user end. Both receivers collect and store satellite data, namely carrier phase measurements. The Base receiver knows its exact latitude and longitudinal position because of the coordinated point that it is set up over while the Rover only knows its approximate latitude and longitudinal position.

To improve the positional accuracy at the Rover the phase measurements at the Base are analysed and a correction is calculated. This correction is then broadcast to the Rover using radio link. RTK surveys traditionally broadcast the correction through the use of radio frequencies such as Ultra High Frequency (UHF). The Rover then combines the phase measurements it has collected with the correctional information it has received from the base. The onboard computer in the Rover then processes the combined data and calculates the corrected Rover coordinates. The correction computed by the Base is simply the difference between the known coordinate values of the Base and the calculated coordinate value. This correction must then be distributed to the Roving receiver using either Radio Link or NTRIP and it is at this stage the latency times and noise can be calculated to determine the affect on RTK point precisions.

2.3 *NTRIP Overview*

2.3.1 *Transmission Technique*

The method of transmitting GNSS correctional data from a Base receiver to a Roving receiver through an internet connection is the next generation of technology for surveying. This process differs slightly in that the Base receiver must be connected to a central server rather than externally set up in isolation on a point with published coordinate values. The logging of data from satellites and the correction calculations are exactly the same as the radio link method, however once the correction has been calculated the data is transmitted to the central server where it is allocated a unique Internet Protocol (IP) address and then distributed through an internet connection to the Roving receiver. The Roving receiver must access the internet through a wireless connection and be registered as a destination source for the broadcast packets of correctional data. The correctional data is received by the Rover and applied to what it believed to be the actual position. When the final adjustment is made the correct position is determined.

2.3.2 *NTRIP Development*

During the last ten years, a significant number of technological advancements have occurred throughout the world. One of the most significant developments has been the improvement to communication networks, resulting in the enormous growth of applications related to social networking.

The growth in communications technology has provided the platform for a new era of Global Positioning System (GPS) Surveying. With the telecommunication industry constantly increasing the capabilities and extent of networks (mobile phone and internet), surveyors have learned to utilise these networks to transmit real time GNSS correctional data, hence the development of an internet method of transmitting GNSS correctional data.

A United States organisation, the Radio Technical Commission for Maritime Services (RTCM), works within a special Committee No. 104 (SC-104) with the standards for real time transfer of observations of satellite based navigation systems for differential applications. The special committee is responsible for RTCM standards for differential GNSS (Lenz 2004). RTCM is responsible for producing data communication formats of GNSS data which meet the international standards for navigation systems. The original version of the GNSS format dated back to 1983 where it attempted to achieve five metre accuracies with Differential GPS surveying equipment. Since then the special committee 104 has made many modifications to the format which is now supported by the internet protocol. Currently, version three is available and is aimed at improving the networked RTK system.

In 2004, the Federal Agency for Cartography and Geodesy in Germany (BKG) in partnership with the University of Dortmund and Trimble launched the Networked Transport of RTCM via Internet Protocol (NTRIP). This development has provided many benefits such as solving radio link problems, sharing real time GNSS corrections simultaneously to a wider user base and provide greater geographic coverage for RTK surveys such as Global information System and cadastre mapping.

Since the launch of NTRIP, GNSS correctional data has been able to be streamed or transferred from the Base to the Rover via the Internet Protocol (IP). Streaming the data requires it to be divided into data packets, with the size of the packet being referred to in bits or bytes depending on size. 1024 bits of data equal one kilobit. 1024 bytes of data equal one kilobyte or eight kilobits of data. 1024 kilobytes of data equal one megabyte or 8192 kilobits of data. Kilobits of data are the smallest size data packets and megabytes are the largest.

Each packet of correctional data that is transmitted has a unique IP address which is recognised by the destination source (Roving GNSS Receiver). The data space required to stream data packets is referred to as its bandwidth. For example the bandwidth required to stream GNSS correctional data is five kilo bits per second (Kbps), whereas the bandwidth required to stream a movie is three mega bits per second (Mbps). Therefore streaming a movie requires six hundred times more bandwidth than GNSS correctional data.

The purpose of the NTRIP development is to provide an alternative to the current radio link methods of data transmission (Lenz, 2004). NTRIP's development was centred on a network of Continuously Operating Reference Stations (CORS) strategically positioned throughout Germany. The position of the CORS stations meant that the RTK surveying application would be more widely available to the surveying industry. The increase in use of the RTK application and the regular annoyances associated with radio link signals has resulted in the development of NTRIP.

The NTRIP system operates based on GNSS data being logged by a CORS base station, the corrections are processed and forwarded to a central unit (server) where the correctional data is divided into packets in readiness to be broadcast to a roving unit. Figure 1.1 illustrates the different phases and flow of GNSS data using NTRIP.

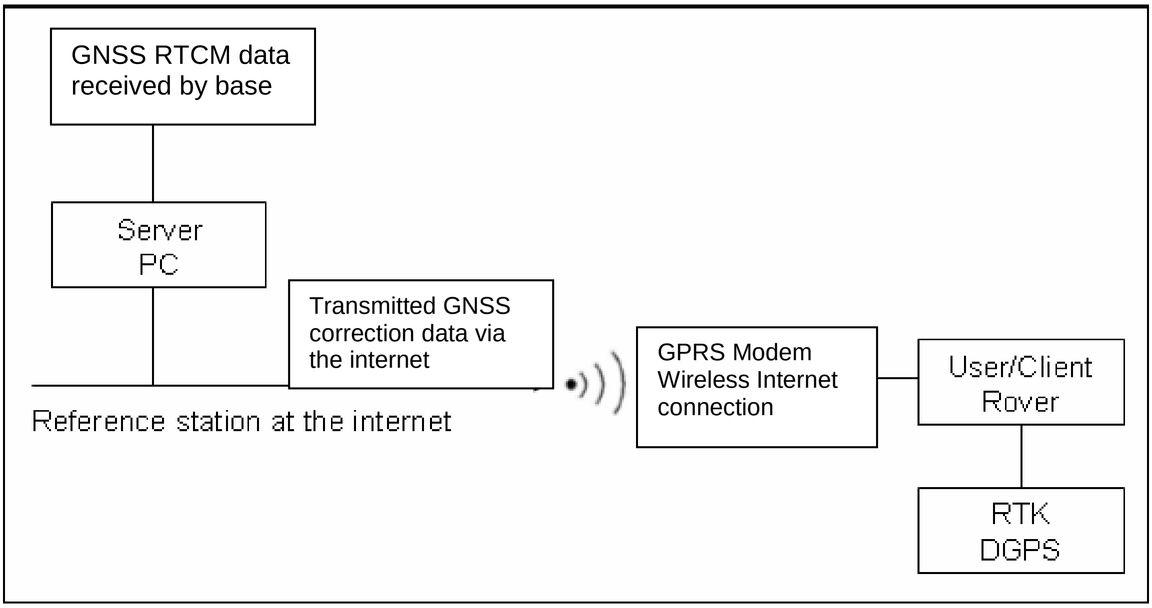

Figure 1.1 GNSS data stream on the internet
Source : Lenz, 2004

To receive the NTRIP data packets, the Roving receiver must connect to the internet using mobile communication networks such as Global System for Mobile Communications (GSM), General Packet Radio Service (GPRS), Enhanced Datarate for Global Evolution (EDGE) and it is anticipated that transmission will soon be available via the Universal Mobile Telephone System (UMTS). These methods of communication are described in detail below.

- **GSM:** is a public digital cellular network using techniques for multiplexing and a transmission band of approximately 900 MHz. A GSM network provides telephony services and data communication in circuit and/or package mode. The European GSM version uses an 1800 MHZ band, while the United States operates a 1900 MHz band network.

- **GPRS:** is a global system for mobile communication that increases the channel speed from 9.600 to 14.400 bits per second (bps). A GPRS system also utilises the ability to compress data which increases channel speed. With GPRS, mobile data transmissions can be as fast as 115.000 bps using the existing GSM base station infrastructure.
- **EDGE:** is a new modulation scheme, it is more bandwidth efficient in its use of standard GSM networks. The modulation scheme is called 8PSK (8 Phase Shift Keying modulation) and enables each pulse to carry 3 bits of information compared to GPRS which has 1 bit per pulse rate. Overall this enables EDGE to increase the data rate of existing GSM systems by a factor of three (384 Kbit/s).

- **UMTS:** is often referred to as the third European generation of the mobile communication system. The spectrum for UMTS ranges between 1900 MHz to 2025 MHz and 2110 MHz to 2200 MHz. UMTS offers a 'multimedia' choice enabling a simultaneous transfer of speech, pictures and data with a maximum data rate of 2 Mbit/s. Transmission of speech and low data rate applications will continue to be carried out by GSM.

Source : Lenz, 2004

To receive correctional data at the Rover, the mobile modem must first be defined as a destination source by the client software. This allows the Rover to receive the designated correctional data packages. Once a wireless internet connection is established, NTRIP GNSS correctional data can be received by the Roving receiver and real time surveying can commence.

2.3.3 *NTRIP Review*

Although the NTRIP application has been in operation for almost 10 years, improvements to the technology is advancing constantly and it is therefore imperative that rigorous testing be done to document its achievable precisions. Weber et al (2004) conducted field research into the accuracy and latency of GNSS correctional data using a wired internet connection, a GPRS and GSM mobile network connection.

Results published by Weber et al (2004) indicate that there is a latency period in the transmission of GNSS correctional data in all three methods. With a wired internet connection the average latency in data is 1.71 seconds +/- 0.41. The latency when using the GPRS wireless modem is only 0.28 seconds slower than the wired internet, therefore latency is 1.99 seconds +/-0.41. The GSM wireless modem results show that it had the highest latency period, an average of 3.6 seconds +/- 0.75. Weber et al (2004) also indicated that the maximum latency for all three tested internet methods were double the average latency.

Reflection upon some anecdotal evidence by an experienced surveyor using NTRIP with a GSM mobile modem was that it caused a high degree of what seemed to be positional uncertainty. At this time it was unclear what caused this and initiated the need for further investigation. Upon further research it is possible that I was experiencing the affects of latency. Weber et al (2004) also reported that for RTK NTRIP applications the achievable accuracies were not degraded, however these findings were not published and there is no evidence to suggest that the results were compared to conventional methods of radio link which would have provided a benchmark for the findings.

The noise and latency of data is of concern when real time surveying applications rely on instantaneous and quality corrections. Latency of data can cause degradation of the correction; poor precisions may result which is of particular concern for set out, cadastral surveys and machine guidance operations that rely so heavily on precise real time corrections. These poor precisions are simply vast changes in delta Easting and Northing co-ordinates for any given point which creates doubt in the mind of the surveyor as to the quality of his/her work.

At the Map Asia conference, Dammalage, Srinuandee, Samarakoon, Susaki, Srisahakit (2009) reported on the achievable positional accuracies of NTRIP RTK compared to conventional radio link RTK methods. The results indicated that over a five kilometre baseline the observed accuracy of RTK using NTRIP was 0.162m and radio link was 0.161m. Other findings indicate that over a fifteen kilometre baseline the observed accuracy of RTK using the NTRIP was 0.152m, compared to radio link data which was 0.160m. Dammalage et al (2009) results of 0.162m accuracy for RTK using NTRIP over a five kilometre baseline is poor, and is an indication that the points measured where not accurately coordinated marks or the positional accuracy of the equipment is of poor standard.

Interestingly, even though the data collected by Dammalage et al (2009) only report on horizontal accuracies and not horizontal precisions, it was reported that NTRIP data was suspect to large latency times which was discovered during the analysis of the data sets. Do high latency times in data transmission contribute to poor precisions? Weber et al (2004) stated that high latencies of correctional data can significantly degrade data quality however, if data degradation was negligible, precisions of 0.01-0.02m were achievable. These findings are more in line with expected results and most manufacturers stated horizontal precisions.

Chen, Li and Weber (2004) conducted research on the positional accuracy of RTK correctional data when using NTRIP and the system communications ability of GPRS and GSM mobile modems. One test involved a static measurement of GNSS data with no obstructions, aimed at demonstrating the possible positional accuracies using GPRS. The other test involved two scenarios, driving a car at speeds up to 80 km/hr while collecting RTK correctional data while using NTRIP modems such as the GPRS and GSM modems. The route for this test involved passing beneath four bridges. This test was aimed at determining the effectiveness and stability of the GPRS connection by measuring the ability to re-initialise and connect with the network.

The results of the static test indicated that positional accuracy when using the GPRS modem to collect GNSS correctional data transmitted using NTRIP was three centimetres at 95% confidence levels, and similar with the GSM modem. These results are slightly worse than the standards set out in ICSM's – Special Publication 1 for RTK surveying which states at less than one kilometre and at the lowest class of precision the expected precision is one and a half centimetres; however the results presented by Chen et al (2004) have not been directly compared to radio link methods of data transmission.

Interestingly, Chen et al (2004) discovered that the GPRS network was less reliable in its communication ability than GSM. Chen et al (2004) findings were validated by research that indicates packet data transmitted via GSM has the same priority as voice data and is therefore allocated a time slot in the transmission network. The GPRS packet data does not have the same priority as voice data and is not allocated a time slot, hence the lack of connectivity by the GPRS modem during the driving test. If the majority of communication across a network consists of voice data then correctional data packages transmitted with the use of a GPRS modem will most likely be delayed. This is an important point because the delay in transmission of GNSS correctional data may be directly related to the type of modem that is being used to connect to the internet and could result in times of inconsistent transmission.

Inglis (2006) conducted an evaluation of the VRS-RTK GPS latency in a dynamic environment with GSM wireless connections. The testing procedure for this evaluation involved driving at speeds of 3km/hr with a GNSS receiver mounted on the car and a barcode reader to trigger the measuring process. There were some problems encountered using the barcode reader during the testing, and it was deemed that the device did not provide a satisfactory means of testing latency. However, from the results gathered it could be shown that there was some latency with RTK measurements in a dynamic environment.

Future improvements to phone and internet networks such as the National Broadband Network will hopefully provide benefits to the transmission, speed and consistency of internet data. As manufacturers benefit from network improvements, research and development in modem types and capabilities will result in advantages for NTRIP RTK.

2.4 *Summary*

The review of literature has outlined a need to compare the noise and timings of GNSS correctional data that has been transmitted using radio link and the internet. It was found that data transmitted using NTRIP suffered latency periods with respect to data being received at the Rover end. It is also unclear as to whether the precision of the data is affected by latency.

The research also identified that the type of modem used to connect to the internet can impact the latency period of GNSS correctional data.

3.0 Methodology

3.1 *Introduction*

This chapter will outline the methodology used for conducting the testing programme and any procedural notes. Where necessary it will highlight the standards required to be met in order to obtain high data integrity.

The aim of this chapter is to provide a detailed procedural list of operations required to fulfil the testing programme. This must be clear and unambiguous and enable other persons to carry out the same tests.

The methodology will comprise the necessary sequential procedures that must be performed for both tests. It will detail how the GNSS data is collected and processed. It will also identify the required data to come from the tests that will facilitate further analysis and allow results to be determined.

3.2 *Methodology for Experimental Tests*

The project methodology is a crucial component of the field testing programme and is used to ensure that best practice procedures are utilised and data integrity is maintained. The methodology required to conduct this investigative research programme is outlined in Table 1.1 which details specific tasks to be completed and procedures to be followed.

3.2.1 *Noise Tests*

Primarily testing for noise effects involve the measurement of points over existing Permanent Survey Marks (PSM) with published coordinate values, using a GNSS Receiver mounted on a tripod using Radio Link and NTRIP methods of communication. At each PSM thirty rapid measurements were taken. Data will be collected in the Trimble TSC2 Data Recorder, connected to the Trimble R8 GNSS receiver using a Bluetooth connection. Three identical tests will be conducted at different distances from the CORS base station. The chosen distances will be less than one kilometre, four kilometres and nine kilometres. For the test at nine kilometres, a repeater transmitter will be erected to enable the radio signal to reach the Roving receiver. Due to the varying elevations of the topography in which the testing took place, the repeater transmitter was a necessary piece of equipment. Each test will be subdivided into two parts: one using radio link, the other using NTRIP.

To provide a level of integrity to the project, two additional existing PSM's will be set out and measured as a check before the commencement of measuring to the three known PSM's. The two additional PSM's will also be measured at the completion of the tests, again as a check to ensure data integrity. These check measurements will be made using what is known as rapid measurements, that is, the point is only measured for 2-3 seconds. This will identify possible errors in the settings of the project and allow alterations to be made before testing commences as well as provide a quality check on all measurements. Table 1.1 provides a detailed outline of the methodology used for the testing of noise. Figure 3.1 illustrates the set up of the noise test.

Table 1.1 Noise Test

RTK - Radio Link and NTRIP Measurements		
NUMBER	**TASK**	**REASONING**
1	Select a suitable site to conduct experiment	1a. Chosen site selected with the assistance of State Government PSM data base; Must enable unrestricted radio link connection
		1b. Chosen site must have suitable mark to measure (First Order Horizontal PSM)
		1c. Chosen site must provide full satellite view, no obstructions - improves data quality
2	Checking all equipment; Data Controller has required survey software and survey styles, the CORS station is operating correctly, all accessories are included eg. Batteries and antenna	2a. Done to minimise the likelihood of poor data collection and the likelihood of technical problems occurring in the field
3	Load equipment into the truck	3a. Ensures all items on the resource list are loaded and accounted for
4	Arrive at Check Measurement PSM's	4a. Assemble equipment, using the GNSS receiver on a range pole
5	Turn on Trimble Data Recorder #1, connect to Receiver using bluetooth, select the RTK survey style; check survey settings	5a. Preparing for stake out of check PSM's
6	Input known Easting and Northing values of check PSM's	6a. Set Out PSM and store a rapid point measurement over the mark; ensure the results are of adequate accuracy for RTK surveying
7	Arrive at site and place all necessary signage	7a. Done to minimise risk
8	Set tripod and Rover over mark and turn on Rover	8a. Important to position the Rover directly over the mark and ensure it is level
9	Turn on Trimble Data Recorder #1, connect to Receiver using bluetooth, select the RTK CORS survey style; check survey settings	9a. RTK style is selected to measure points when using radio link to transmit GNSS corrections; settings must be checked to ensure elevation mask is 13 degrees
10	Select Survey menu, then start survey	10a. Select start survey allow time for the data recorder to initialise; Data will be collected in the data recorder
11	Select Survey menu, then measure points	11a. The point will be measured 30 times using the rapid measurement mode 11b. When measuring is complete, end survey and keep Rover turned on
12	Repeat steps 9 to 11 with Trimble Data Recorder #2 with NTRIP	

Figure 3.1 The set up of the static point measurement technique at PSM 103109

When all the required data is collected, it will be brought to the office and downloaded into a software program called Trimble Business Centre 2 where it can be processed. This program allows collected GNSS data to be viewed systematically for errors in satellite signals and assess the baselines to determine the calculated values of the marks measured. The data expected will be in the form of coordinates (Easting and Northing). The coordinate data from each test will be exported from Trimble Business Centre 2 as a *csv file to enable the manipulation of the data in Microsoft Excel.

3.2.2 *Latency Tests*

Testing the latency of GNSS correctional data transmitted to a Roving receiver whilst in an RTK surveying mode is very difficult. Previous tests performed on NTRIP have not specifically investigated latency and have only reported on it as being observed during the process of other testing, with no definitive data collected. RTK surveying applications are limited in regard to the type of data that can be extracted from each measurement, specifically time tags. Other surveying applications such as Static surveys differ dramatically from RTK surveying, in that each measurement contains a host of information such as logging rate, epoch data and time tagged measurements of both the Base station and the Roving receiver. This would be extremely useful in determining when GNSS correction data left the Base and when it was received at the Rover.

RTK surveying is different to Static surveys because the Base station or CORS has a published latitude and longitudinal value and the Roving receiver only knows its approximate position and is constantly being transmitted GNSS corrections from the Base station for its real time position. Static surveys don't receive real time corrections from the Base station. The data is post-processed and calculated after the surveying is complete with the use of specific software.

The testing procedure for latency involved driving a car at set speeds with a Roving receiver on the roof and recording points whilst the car was in motion. The start line position was surveyed to determine its coordinates. As the vehicle passed the starting line the measure button was pressed and a point was stored some distance past the starting line. This distance from the starting point to the stored point is what will reflect the latency in the signal. This process was completed thirty times at 50km/hr with Radio Link and another thirty times with NTRIP. The process was performed again at a speed of 40km/hr.

Table 1.2 outlines in detail the methodology used to set up and perform the tests to determine latency. Figure 3.2 illustrates the set up of the Roving receiver on the car roof to measure the required points.

Table 1.2 Latency Test

Part B	***LATENCY TEST***	
1	Find suitable location for driving test to determine latency	1a. Safety reasons
2	Place witches hats at the start line and measure each to acquire coordinates	2a. The coordinates of the start line must be known in relation the driving measurements
3	Laps of the test area are done to engage the 40km/hr cruise control setting	3a. This is done to eliminate the human error of attempting to maintain a set speed
4	Place GNSS receiver on a magnetised car mount on car roof above drivers head	4a. To enable full view of satellites
5	Turn on Trimble Data Recorder #1, connect to Receiver using bluetooth and select RTK CORS survey style; check survey settings	5a. Allow time for initialisation
6	At the top of each run a point is measured to ensure the freedom of measurement is possible	6a. This is done to ensure the Data Recorder or the CORS hasn't malfunctioned
7	At the constant speed, as the car passing the start line the measure button is pressed	7a. There will be some human error
8	Repeat steps 6 – 7, 30 times with Radio Link at 40km/hr	8a. 30 measurements are taken to enable a distinct pattern of measurements to be detected
9	Repeat step 3 to engage the 50km/hr cruise control setting	
10	Repeat steps 6 – 7, 30 times with Radio Link at 50km/hr	10a. 30 measurements are taken to enable a distinct pattern of measurements to be detected
11	Repeat steps 6 – 10 with Trimble Data Recorder #2 with NTRIP	

Figure 3.2 The set up of the latency test with the GNSS receiver mounted on the car roof

3.3 *Summary*

The methodology used for the field test programme is clearly detailed and would enable other persons to conduct their own test. The programme is designed to provide suitable data for the purpose of calculating noise and latency of GNSS correctional data transmitted using radio link and the internet. The likely results from this testing programme will be in the form of residuals for the distance from the mean coordinate which can be simplified down to a precision such as 3mm +/- 2 parts per million. The latency data is expected to provide results on the timings for both Radio Link and NTRIP which will be calculated from the distance measurement from the start line to the stored point and converted to a latency time.

4.0 Results

4.1 *Introduction*

This chapter will include the results of the measurements taken in the field testing programme which comprises of two experiments. These results will assist in the determination of the noise and latency experienced by Radio Link and NTRIP RTK data.

The aim of this chapter is to compile the results from the field testing programme, make comparisons, determine errors, and calculate residuals that will enable accurate conclusions to be made.

The results gained from the static observation field experiment will be utilised to calculate the noise and therefore the precision of static measurements of Radio Link and NTRIP RTK data.

The results gained from the second field experiment which involved driving at various speeds will enable the latency in receiving the GNSS correctional data at the Rover to be calculated. This information will then be statistically analysed to determine the standard error and the 95% confidence interval of the each group of measurements.

4.2 *Precision of Static Observations*

The CORS base station used for the RTK static measurements is located on the roof top of the RPS Sunshine Coast office. The Map Grid Australia 1994 (MGA 94) coordinates of the CORS base are Easting 512138.150, Northing 7043184.970, Elevation 18.892, Zone 56. Utilising the CORS base for the field experiment, thirty static measurements were taken at each of the three Permanent Survey Marks (PSM's) used. The data extracted from the static measurements are in the form of local Easting and Northing MGA 94 coordinates which when plotted created a scattering of points about these marks.

Even though the GNSS receiver didn't move during the measuring process, the points are scattered within a few millimetres of each other. The scattering effect is caused by changing satellite geometry, atmospheric errors, ionospheric errors, sun spot activity and user range accuracy which affect the ability of the GNSS receivers to calculate the ambiguity of resolution. Therefore each measurement is slightly different in position.

The coordinate data is used to calculate the mean, the standard deviation of error and the change in Easting and Northing for the set of measurements. The residuals of Easting and Northing about the mean will represent the noise affecting the correctional data transmitted to the Roving receiver.

Prior to the commencement of the static measurements, two other PSM's were measured and checked to ensure that the base coordinates are correct. The results of these measurements can be found in the appendix K and L.

4.2.1 *Baselines of Less than One Kilometre*

At a distance of less than one kilometre from the CORS base the Radio Link data measured at PSM 170100 had a spread of 5mm in Easting and 6mm in Northing. At such close proximity to the CORS base these results demonstrate extremely high horizontal precision, which is backed up by the following standard deviations :

- Easting ±1.34mm
- Northing ±1.68mm

These results indicate that the measurements taken were not subject to substantial outside noise such as atmospheric variations, multipathing and satellite geometry that can greatly impact the precision of Radio Link data.

The NTRIP data collected at PSM 170100 also reflected very good precisions. The spread over the thirty measurements was 6mm in Easting and 9mm in Northing. The standard deviations for the NTRIP measurements are :

- Easting ±1.50mm
- Northing ±2.13mm

Figure 4.1 illustrates the spread of all thirty measurements taken at a baseline of less than one kilometre. The mean of both sets of measurements is highlighted.

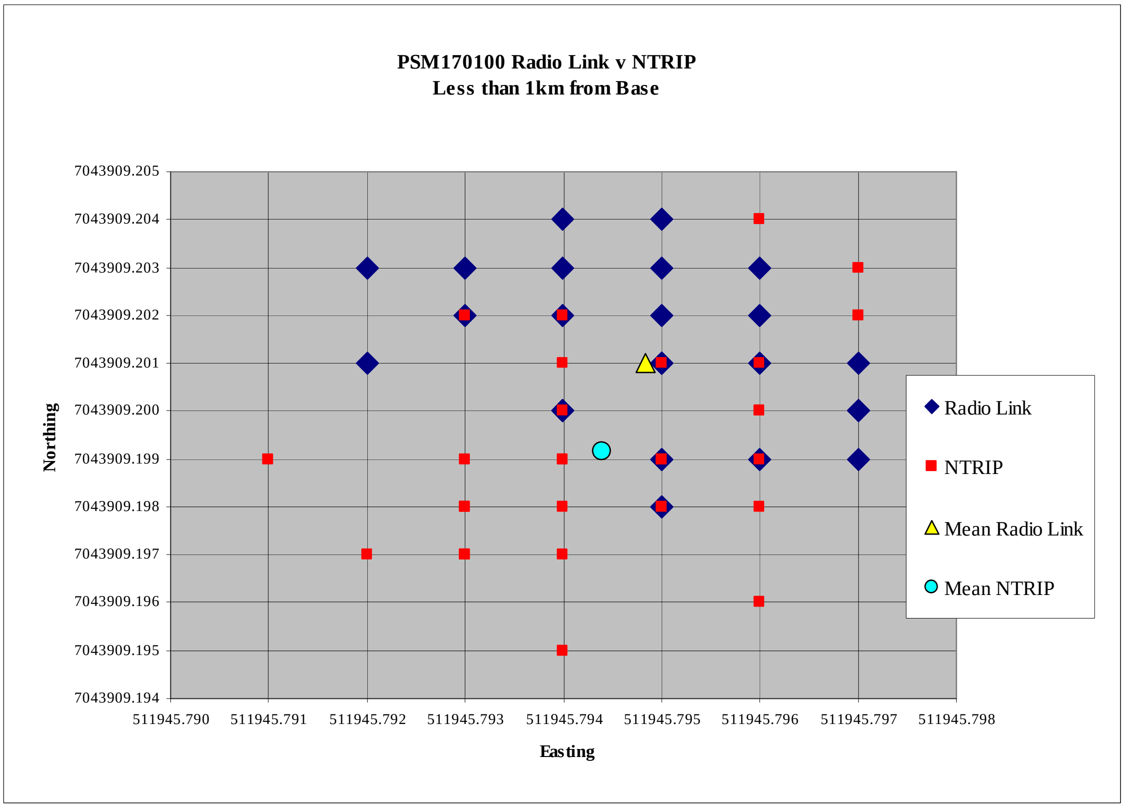

Figure 4.1 Radio Link and NTRIP comparison at less than one kilometre from the CORS.

4.2.2 *Baselines of Four Kilometres*

At a distance of four kilometres from the CORS base the Radio Link data measured at PSM 50649 had a spread of 7mm in Easting and 9mm in Northing. In comparison to the baseline of less than one kilometre the spread of measurements in the four kilometre baseline is greater by 2mm in Easting and 3mm in Northing. The standard deviation of the Radio Link data at four kilometres from the CORS base is :

- Easting ±1.54mm
- Northing ±2.47mm

NTRIP data collected at PSM 50649 experienced more signal noise which was reflected by a greater spread of measurements. The spread in the Easting coordinate was 12mm and 11mm for the Northing. Similarly, the standard deviation for the NTRIP measurements was higher.

- Easting ±3.20mm
- Northing ±3.41mm

Figure 4.2 displays the spread of measurements taken at the baseline length of four kilometres. The mean of both sets of measurements is highlighted.

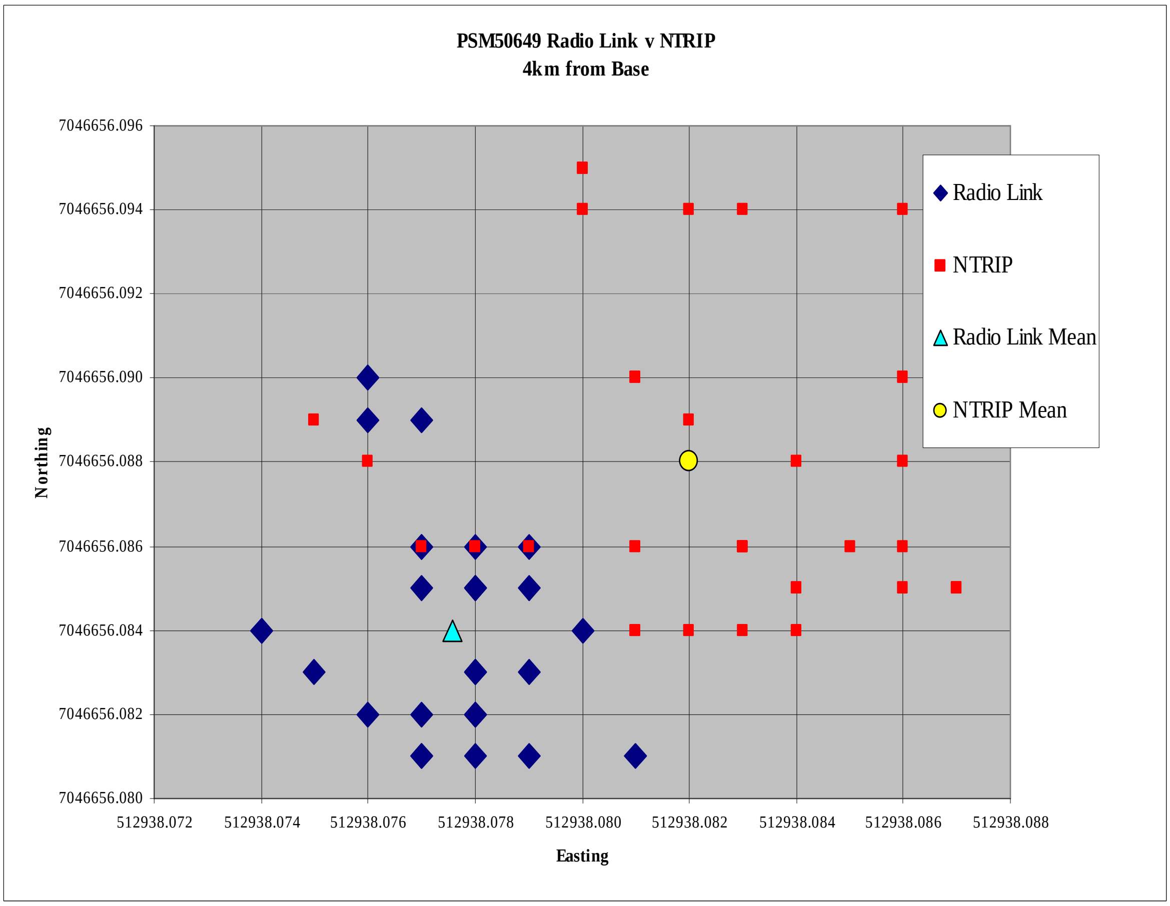

Figure 4.2 Radio Link and NTRIP comparison at a range of four kilometres from the CORS.

4.2.3 *Baselines of Nine Kilometres*

At a distance of nine kilometres from the CORS base the Radio Link data measured at PSM 103109 had a spread of 14mm in Easting and 14mm in Northing. The spread in coordinate values of the thirty measurements has doubled compared to the baselines of one and four kilometres. Subsequently, the standard deviations at a baseline of nine kilometres also reflect the increase in error.

- Easting ±3.23mm
- Northing ±3.51mm

The NTRIP data at a nine kilometre baseline reflects much greater consistency when compared to the four kilometre baseline in terms of spread and standard deviation. The spread in coordinate values at this length baseline is 16mm in Easting and 15mm in Northing. The spread at this baseline length is exactly 4mm larger than those measured at the four kilometre baseline which is negligible; the Radio Link range of measurements had doubled in dispersion from 7mm to 14mm in Easting and 9mm to 14mm in Northing. The standard deviation for NTRIP at a baseline of nine kilometres is:

- Easting ±2.85mm
- Northing ±3.47mm

Figure 4.3 displays the spread of measurements taken at the baseline length of nine kilometres. The mean of both sets of measurements is highlighted.

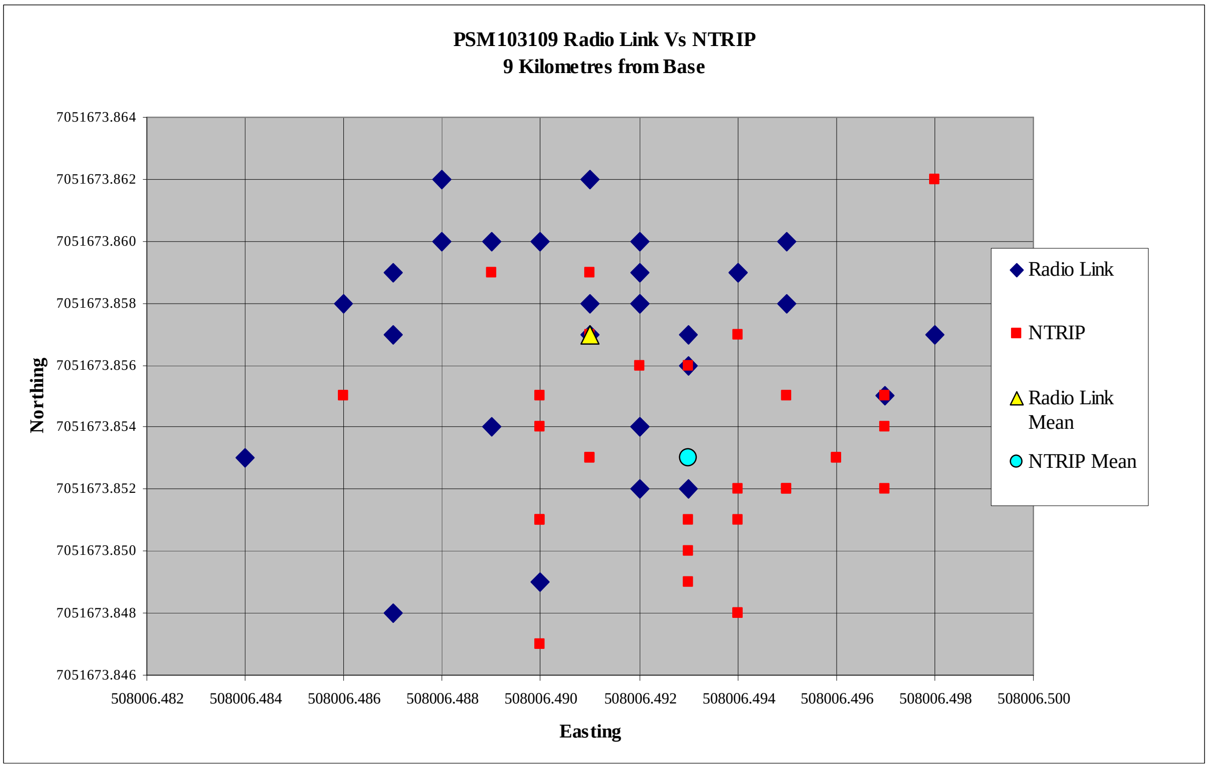

Figure 4.3 Radio Link and NTRIP comparison at a nine kilometre range from the CORS.

4.3 *Latency of GNSS Correction Data*

4.3.1 *Driving Test at Fifty Kilometres Per Hour*

4.3.1.1 *Radio Link*

At a speed of fifty kilometres per hour the mean stored point distance from the start line is 5.487m. The range of distances measured from the start line varied from 0.811m to 11.413m. This range may seem significant, however at fifty kilometres per hour a car can travel 13.889m per second. Therefore, all points have been stored within one second of pressing measure on the data recorder.

The standard deviation of the thirty measurements is ±2.96m, which compared too many surveying tasks is high and is due to a large range of measurements. The top series of data in Figure 4.4 displays all the measured points and the calculated mean for Radio Link data at fifty kilometres per hour.

The distance from the start line to the measured point can be calculated to determine the latency period for the time GNSS corrections are transmitted from the CORS base to the Roving receiver. The top series of data in Figure 4.5 displays the latency distance measured using Radio Link converted to time latency in seconds. The mean latency for Radio Link data at fifty kilometres per hour is 0.395 seconds. This is the time lag between pressing measure on the data recorder at the moment of passing the start line and when the point is actually stored. The maximum latency is 0.822 seconds and the minimum is 0.058 seconds.

4.3.1.2 *NTRIP*

The data collected using the NTRIP method at fifty kilometres per hour revealed a mean stored point distance from the start line of 4.366m. The range of distances from the start line in this set of measurements varied from 0.189m to 7.672m. Again, this range seems excessive.

The standard deviation for the NTRIP data is ±2.26m which is ±0.70m less than the Radio Link data. The bottom series of data in Figure 4.4 displays all the measured distances of the stored points and the calculated mean for NTRIP data at fifty kilometres per hour.

The bottom series of data in Figure 4.5 displays the latency distance measured using NTRIP converted to time latency in seconds. The mean latency for the NTRIP measurements taken at fifty kilometres per hour is 0.314 seconds. The results show that the mean NTRIP point is stored on average 0.081 seconds faster than the Radio Link mean at the same speed. The maximum latency is 0.552 seconds and the minimum is 0.014 seconds.

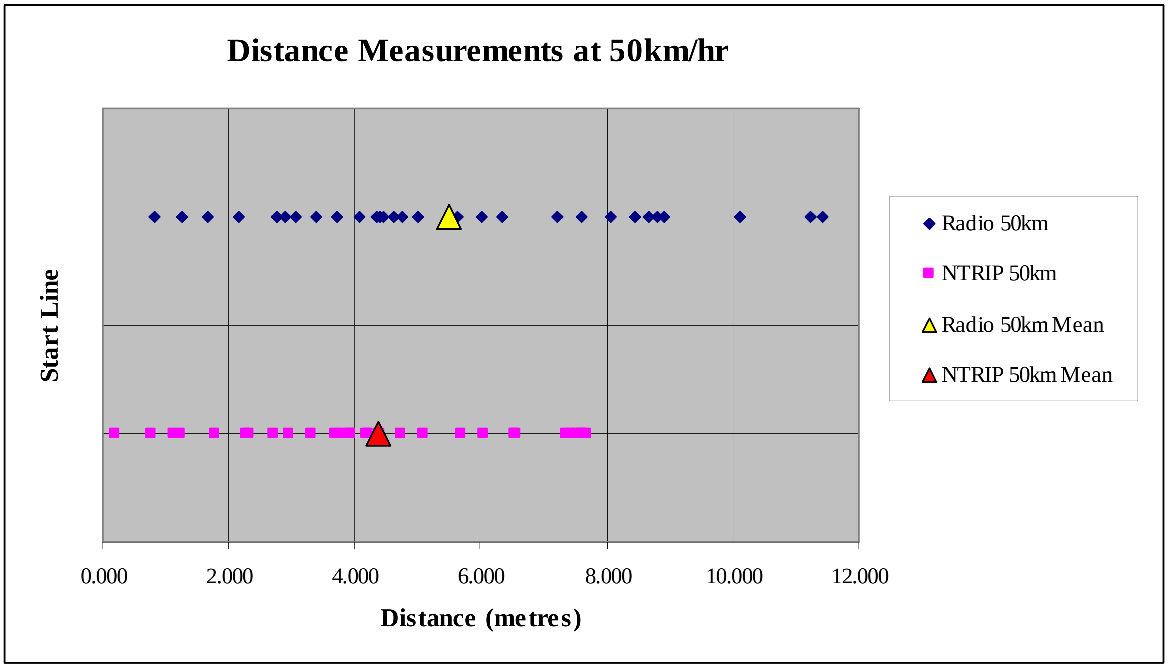

Figure 4.4 Distance measurements to determine latency at fifty kilometres per hour.

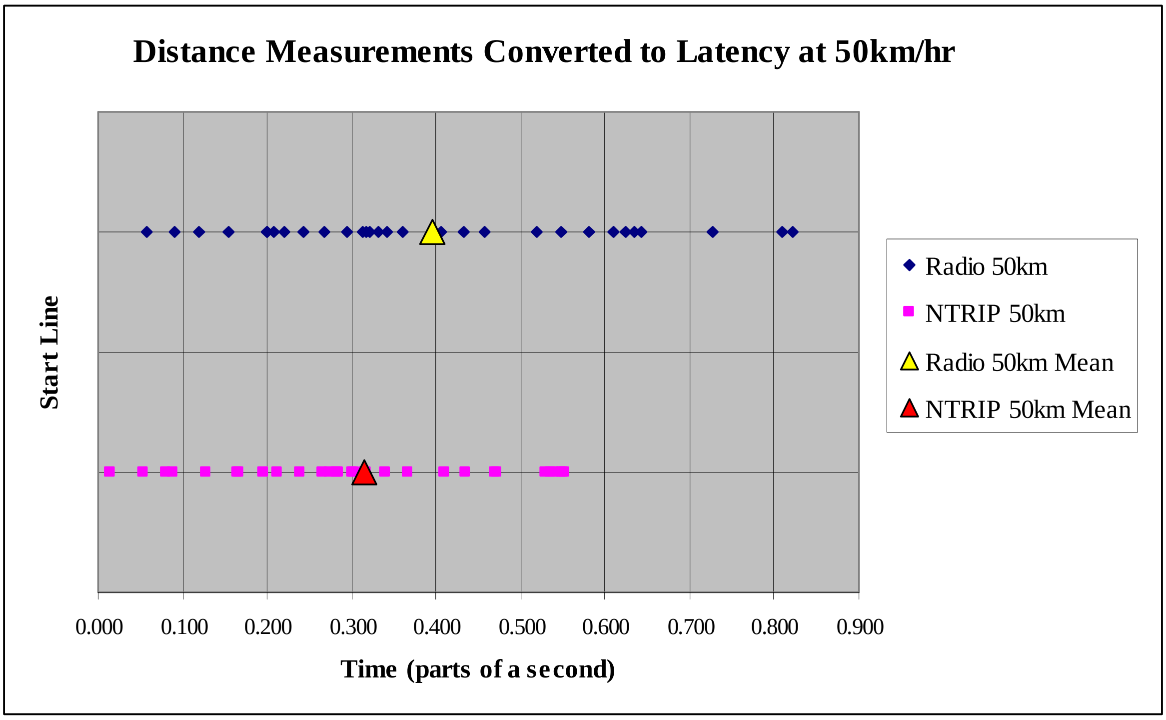

Figure 4.5 Distance measurements converted to latency time at fifty kilometres per hour.

4.3.2 *Driving Test at Forty Kilometres Per Hour*

4.3.2.1 *Radio Link*

At a speed of forty kilometres per hour the mean stored point distance from the start line is 3.549m. The range of distances measured from the start line varied from 0.416m to 7.363m. Similar to the fifty kilometre range, this range seems large as well; however the time difference between the minimum and maximum measurements is just over 0.7 seconds.

The standard deviation of the thirty measurements is ±2.13m. The top series of data in Figure 4.6 displays all the measured distances of the stored points and the calculated mean for Radio Link data at forty kilometres per hour.

The distance from the start line to the measured point can be calculated to determine the latency period for the time GNSS corrections are transmitted from the CORS base to the Roving receiver. The top series of data in Figure 4.7 displays the latency distance measured using Radio Link converted to time latency in seconds. The mean latency for Radio Link data at forty kilometres per hour is 0.319 seconds. This is the time lag between pressing measure on the data recorder at the moment of passing the start line and when the point is actually stored. The maximum latency is 0.663 seconds and the minimum is 0.037 seconds.

4.3.2.2 *NTRIP*

The data collected using the NTRIP method at forty kilometres per hour revealed a mean stored point distance from the start line of 3.971m. The range of distances from the start line in this set of measurements varied from 0.324m to 8.459m.

The standard deviation for the NTRIP data is ±2.16m which is ±0.06m greater than the Radio Link data. The bottom series of data in Figure 4.6 displays all the measured distances of the stored points and the calculated mean for NTRIP data at forty kilometres per hour.

The bottom series of data in Figure 4.7 displays the latency distance measured using NTRIP converted to time latency in seconds. The mean latency for the NTRIP measurements taken at forty kilometres per hour is 0.357 seconds. The results show that the mean NTRIP point is stored on average 0.038 seconds slower than the Radio Link mean at the same speed. The maximum latency is 0.761 seconds and the minimum is 0.029 seconds.

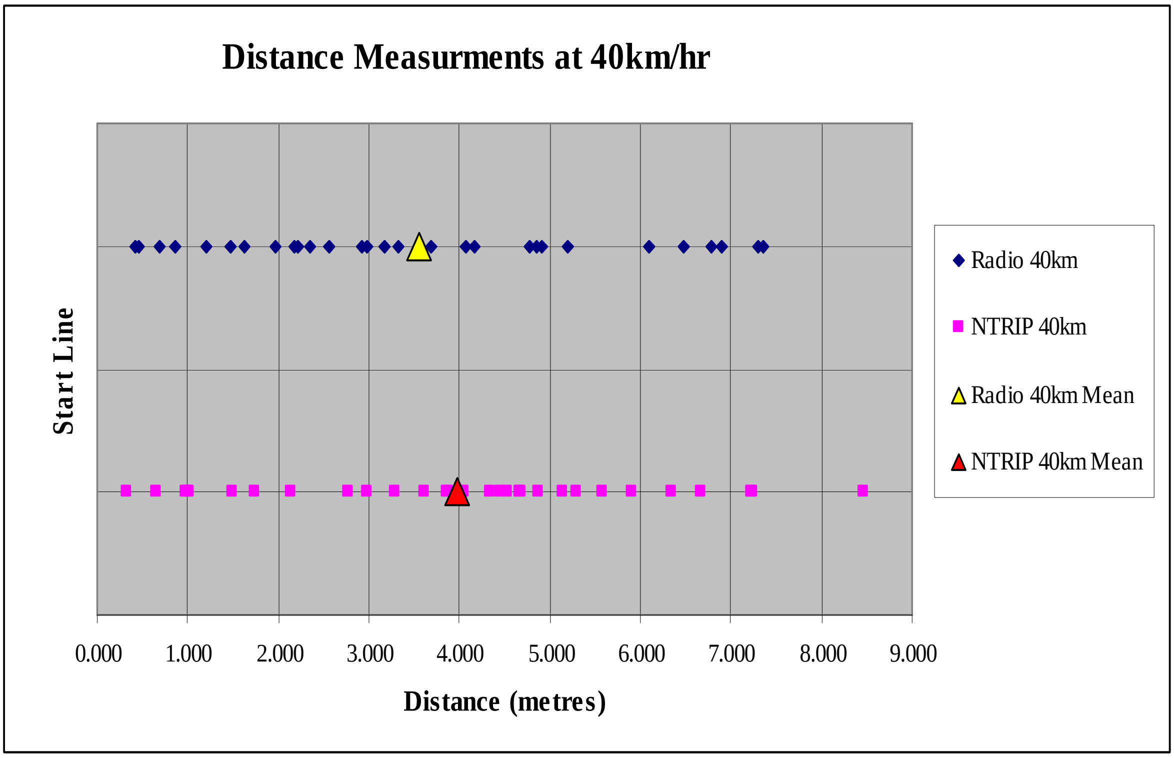

Figure 4.6 Distance measurements to determine latency at forty kilometres per hour.

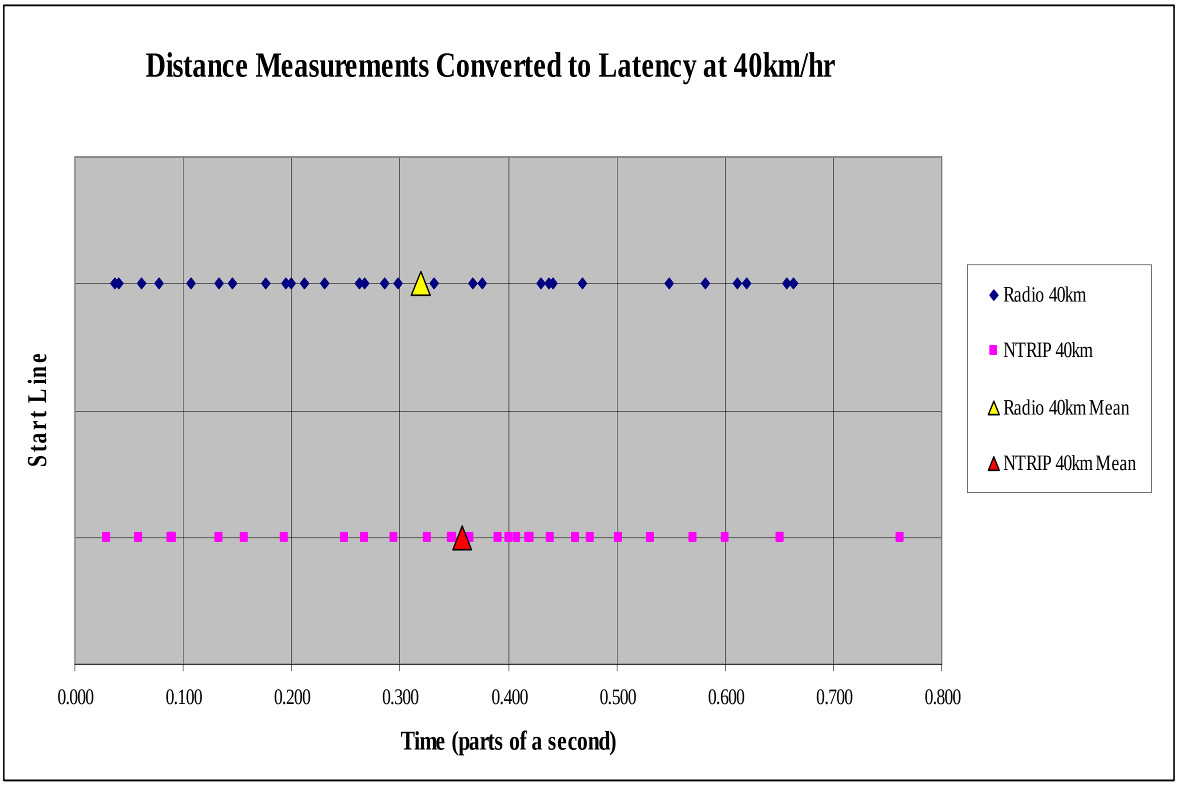

Figure 4.7 Distance measurements converted to latency time at forty kilometres per hour.

4.3.3 *Accuracy of the Static Measurements*

While the accuracy of the static measurements in relation to the known published PSM values was not part of the scope of this dissertation. The data below has been extracted from the data collector and indicates the relative accuracy of each set of measurements. This data was not used in any way as part of the Radio Link and NTRIP analysis.

PSM170100

Radio Link	-	Delta Easting	2mm
	-	Delta Northing	15mm
NTRIP	-	Delta Easting	2mm
	-	Delta Northing	14mm

PSM50649

Radio Link	-	Delta Easting	3mm
	-	Delta Northing	15mm
NTRIP	-	Delta Easting	-1mm
	-	Delta Northing	11mm

PSM103109

Radio Link	-	Delta Easting	-4mm
	-	Delta Northing	17mm
NTRIP	-	Delta Easting	-6mm
	-	Delta Northing	21mm

These results show that the Radio Link and NTRIP measurements have similar accuracies and it is noted that all measurements taken are south of the known values. As the published values of the PSM's are derived by a coordinated network, the accuracies of the Radio Link and NTRIP measurements are beyond the scope of this dissertation and will not be investigated further.

5.0 Analysis

5.1 *Affect of Noise on Horizontal Precisions*

5.1.1 *Range of less than One Kilometre*

At a range of less than one kilometre from the CORS base the results indicated in Figure 4.1 show that Radio Link data and NTRIP data both displayed point measurements of high precision. As a result the mean coordinate values for both sets of data differed by less than 1mm in Easting and less than 2mm in Northing.

To analyse the precisions of the measurements more effectively, the residual vector of each measurement to the mean position was calculated. The residual vector is calculated by the following formula:

$$\text{Residual Vector} = \sqrt{(\Delta E)^2 + (\Delta N)^2}$$

The residual vector calculation enables the number of residual vectors to be plotted in terms of the quantity of residual vectors in each specific residual error category from the mean. Figure 5.1 illustrates the graphing of these grouped residual vectors. The graph shows that the maximum number of vectors in any category of error value was the same for both Radio Link and NTRIP, ten. The range of the vector distances varied from zero to 4mm for Radio Link and to 5mm for NTRIP.

Figure 5.1 clearly shows that the plot of residual vectors for both methods resemble a curve, similar to a bell curve that represents confidence intervals. This emphasises that there is a large number of vector distances centred about the mean vector of 2mm. The 95% confidence interval for the vector distances were calculated to provide a level of integrity to the data and reflect the 95% confidence range in which most vectors will fall. Confidence intervals represent a standard of precision and a level of certainty of measurement with which the surveying industry is familiar.

At the one kilometre range it is shown that noise effects on both methods of transmission are similar. Radio Link has a slightly smaller range of vector distances than NTRIP, which represents a tighter dispersion of measurements. At the one kilometre range the precision of both methods is within 1mm of each other, which in real terms is negligible and the 95% confidence of vector distances is between 1mm and

3mm for both. It can therefore be determined that noise affects on both Radio Link and NTRIP at one kilometre from the CORS are very similar.

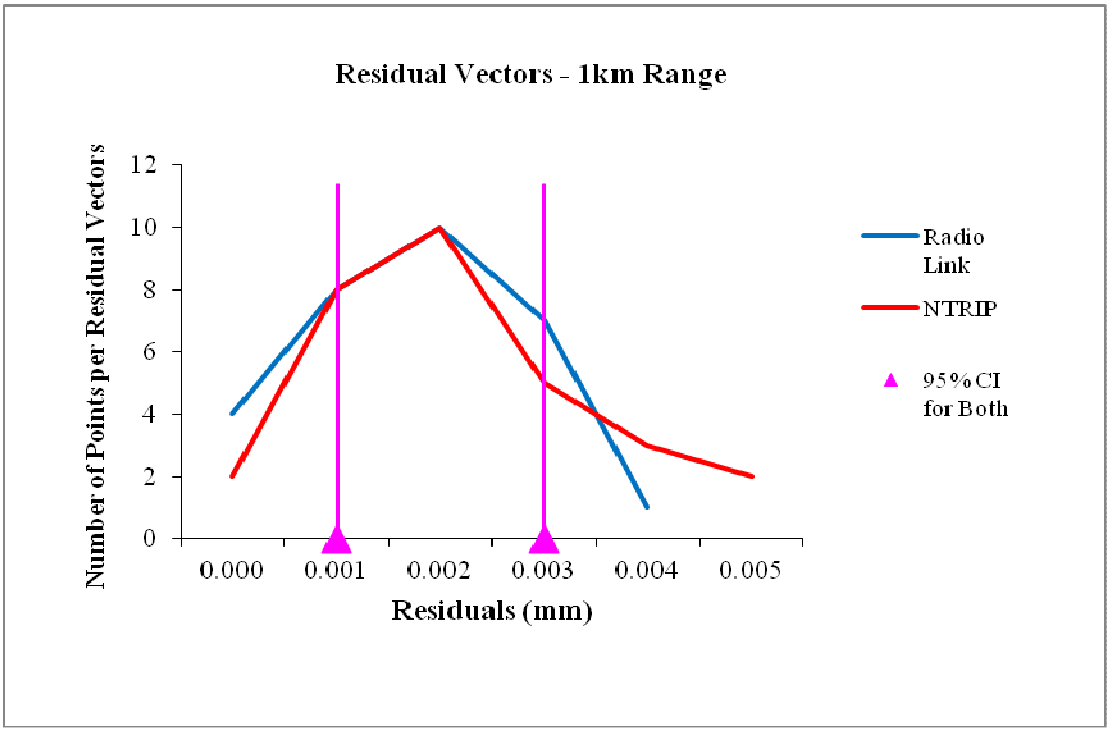

Figure 5.1 Residual vectors at the one kilometre range and 95% confidence.

5.1.2 *Four Kilometre Range*

At the four kilometres range from the CORS base the measurements taken demonstrate that Radio Link data continues to produce results of higher precision than NTRIP which is evident in Figure 4.2. These superior precisions show that Radio Link data is less affected by noise.

NTRIP data at the four kilometre range from the CORS base displayed significant dispersion as illustrated in Figure 4.2. The dispersion of points measured is an indication of the noise that is experienced in the transmission process of GNSS correctional data through the internet to the Roving receiver. Due to no obstructions impeding the Radio Link signal, the correctional data is of high quality and has superior horizontal precisions compared to NTRIP.

Residual vectors of the each measurement are again calculated to determine the number of measurements that fall into specific residual error categories from the mean. Figure

5.2 illustrates the graphing of these grouped residual vectors. This graph shows that the maximum number of vectors in any category of error was nine for Radio Link and eleven for NTRIP. The range of the residual vectors varied from 1mm to 6mm for Radio Link and zero to 7mm for NTRIP.

Figure 5.2 clearly shows that there are a large number of residual vectors in the 1mm and 2mm categories for Radio Link and NTRIP had large numbers in the 2mm and 4mm categories. These results are not as uniform as the results in the one kilometre range, however it does highlight that Radio Link residual vectors are less scattered; as the numbers in each category simply taper off in accordance with the increase in vector distance. The NTRIP residual vectors are certainly more up and down as illustrated in Figure 5.2. The plot illustrates the unevenness of the number of residual vectors in each category of error. They are more random and this resembles the same scattered dispersement as in Figure 4.2.

The 95% confidence interval for the residual vectors was calculated to provide a level of integrity to the data and reflect the range in which most vectors will fall. At the four kilometre range, the 95% confidence of the Radio Link residual vectors was between 2mm and 4mm. The 95% confidence of the NTRIP residual vectors was between 2mm and 6mm which is one third larger than Radio Link. This increase in confidence range demonstrates that noise has a greater affect on the horizontal precisions of NTRIP data at a range of four kilometres from the CORS base.

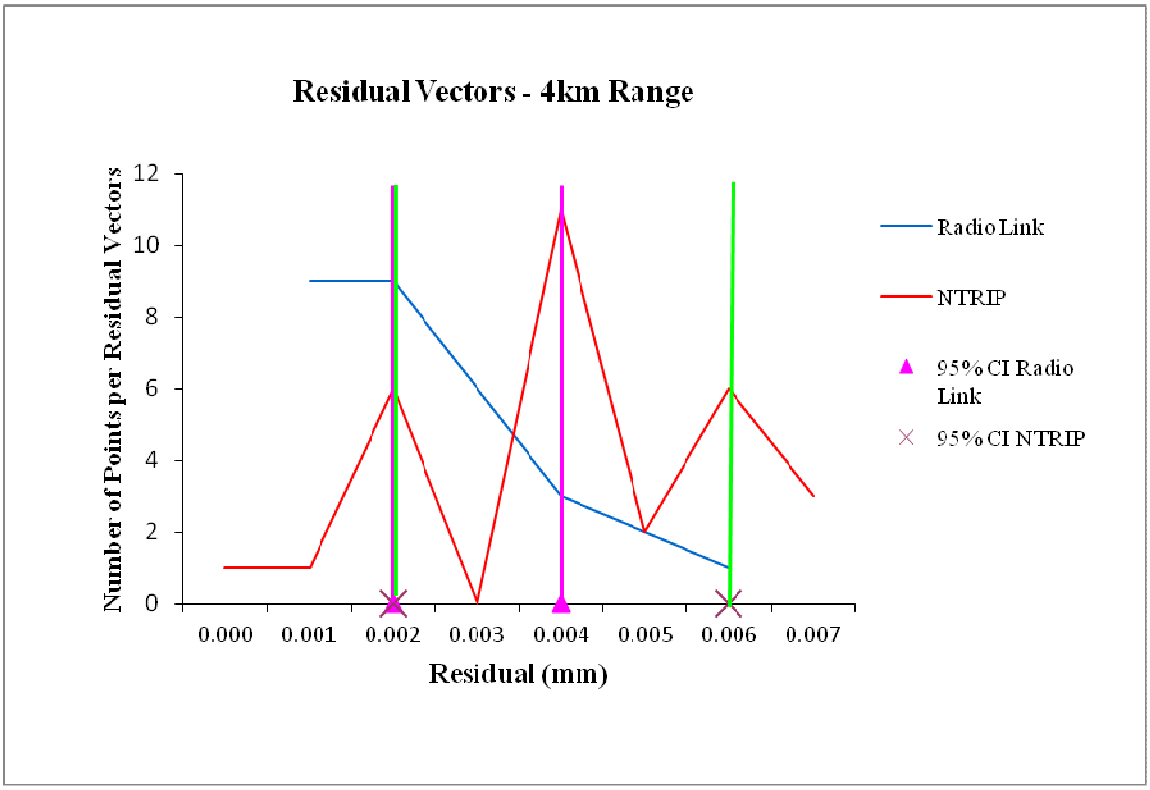

Figure 5.2 Residual vectors at the 4 kilometre range and 95% confidence.

5.1.3 *Nine Kilometre Range*

At a range of nine kilometres from the CORS base it is evident from Figure 4.3 that the range of measurements of both Radio Link and NTRIP data is similar. Analysis of the NTRIP data reveals that the range and standard deviation of this set of measurements is actually similar to the NTRIP measurements at the four kilometre range. Conversely, the range of the Radio Link measurements have progressively increased as the baseline length has increased.

Residual vectors of the each measurement are again calculated to determine the number of measurements that fall into specific residual error distances from the mean. Figure 5.3 illustrates the graphing of these grouped residual vectors. This graph shows a similar uniformity to that of the one kilometre range in that it more resembles a bell curve. The maximum number of vectors in any range of error values was eight for Radio Link and nine for NTRIP. The range of the residual vectors varied from zero to 10mm for Radio Link and 1mm to 10mm for NTRIP.

Figure 5.3 clearly shows a large number of residual vectors within the 95% confidence range for both methods, hence the shape of the curve. Interestingly, the confidence interval for Radio Link and NTRIP at nine kilometres is identical (2mm to 6mm vector distance), therefore it can be said that the affect of noise on horizontal precisions of both Radio Link and NTRIP are equal. It is also important to note that the horizontal precisions displayed by both methods at the nine kilometre range are well within the stated manufacturers and survey standard precisions of 10mm +/- 2ppm.

The other interesting observation is that the 95% confidence intervals of NTRIP at four kilometres and nine kilometres are identical with a range of 2mm to 6mm. It is therefore strongly suspected that noise affects on GNSS corrections transmitted using NTRIP remain constant as the distance in range from the CORS base increases.

Conversely, there is a notable increase in the confidence levels and the range of vector distances as baseline lengths increase for Radio Link measurements. The range of vector distances increased from 4mm at one kilometre, 5mm at four kilometres and 10mm at nine kilometres. This illustrates that horizontal precisions worsen from the affects of noise as baseline length increases.

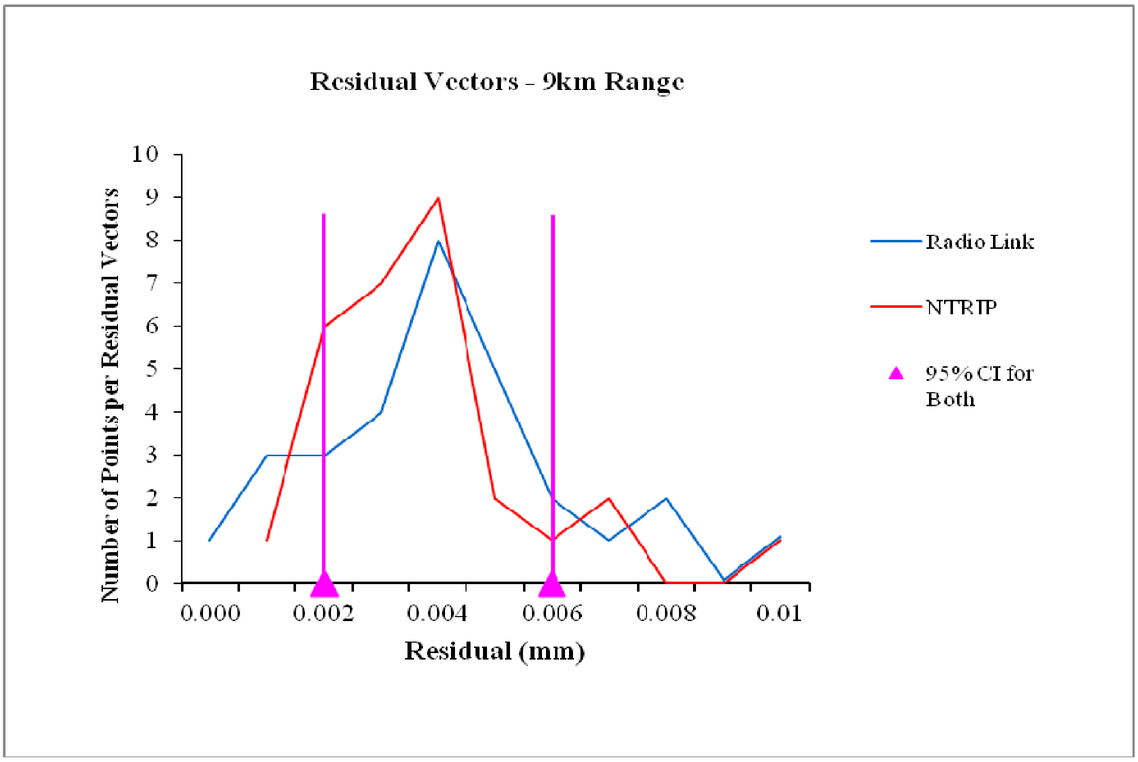

Figure 5.3 Residual vectors at 9 kilometres and 95% confidence

5.2 *Latency Analysis*

The results from the latency tests show that the spread of distance measurements from the start line to the stored point varies dramatically from nearly twelve metres down to just under a metre. However, when the mean distance is converted to a latency time it is noted that the mean latency for each set of data is within the range of 0.3 and 0.4 parts of a second as illustrated in Figure 5.4.

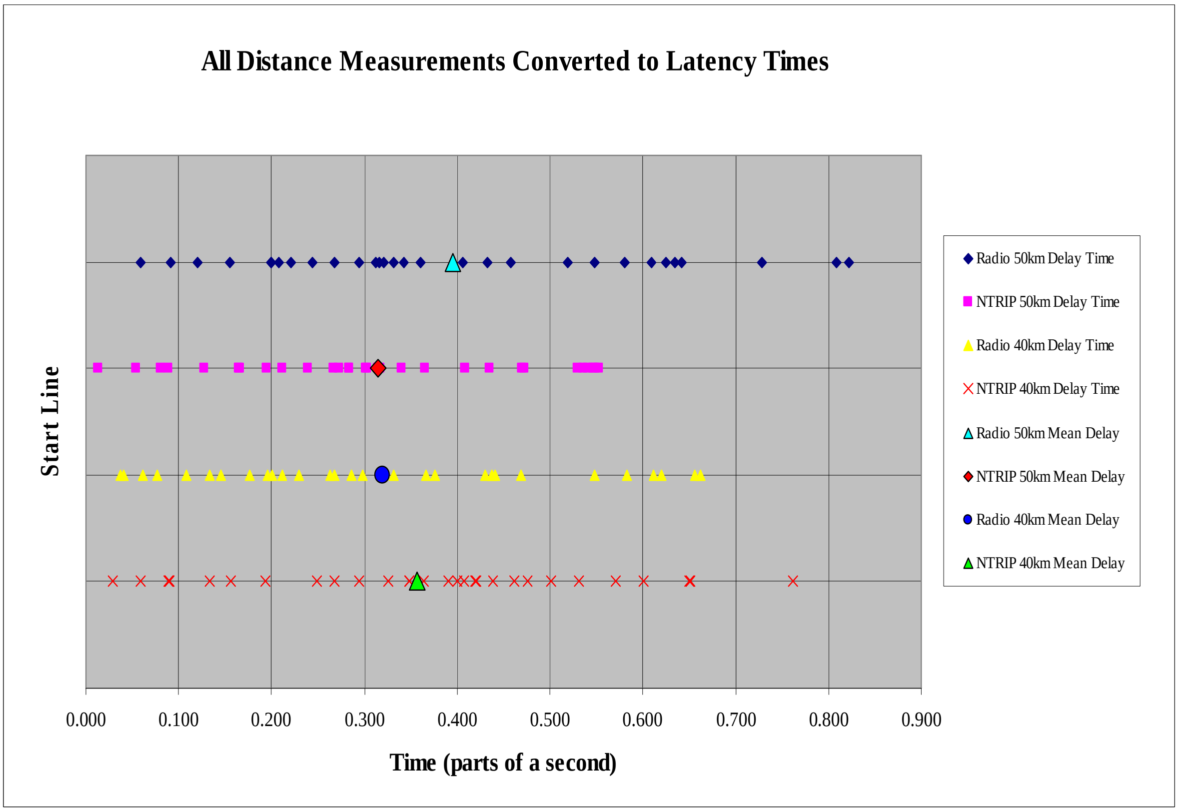

Figure 5.4 All measurements from when the point is measured to when the point is stored, converted to a latency time.

In a more simplistic version of what is actually occurring in the latency tests Figure 5.5 illustrates that as the Roving receiver (which is travelling at a set speed) passes the start line, the measure button is pressed. As the GNSS correction data is affected by a delay time, the point measured is actually stored some metres past the start line.

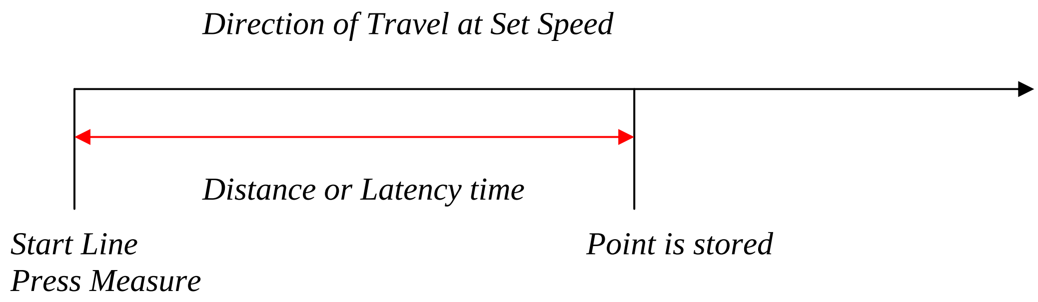

Figure 5.5 Illustration of the affect of latency on RTK surveyed points.

Interestingly, in the fifty kilometre per hour test, the results show that Radio Link data had a larger spread of latency than NTRIP which is unexpected considering the literature review prior to commencement. Webber et al (2004) published that NTRIP data had an average latency of 1.99 seconds ±0.41, thus considering a car travelling at fifty kilometres an hour can travel 13.889m per second, the results indicate that the average latency of all measurements taken using NTRIP is 0.6 seconds ±0.16.

The larger latency spread of the Radio Link data at fifty kilometres per hour compared to NTRIP data is also interesting given that this test was conducted at a similar distance from the CORS base as the one kilometre static baseline measurements. The Radio Link static measurements displayed high precision and therefore it was expected that the radio signal was strong and unaffected by noise, however in this instance the radio signal strength hasn't equated to minimal latency times.

The forty kilometre per hour tests with a car travelling at 11.111m per second show that latency spreads are similar for both Radio Link and NTRIP and there is only a difference of 0.038 seconds in the mean latency.

While the measurements taken were subject to some extent of human error given that the measure button had to be pressed as the car drove over the start line, and even if the results were given some leniency (±2.0m) because of this, the data gathered using NTRIP demonstrates that technology has improved and GNSS correction latency times have reducing significantly since NTRIP's inception in 2004.

To provide some level of certainty in the delay time of when a point is measured and when it is stored a 95% confidence interval calculation is performed on both sets of data. The following 95% confidence levels have been calculated :

Table 1.3 95% Confidence Levels for Latency

Transmission Method	Speed	95% Confidence Lower	95% Confidence Upper
Radio Link – distance	50km	2.583m	8.389m
Radio Link – latency	50km	0.186sec	0.604sec
NTRIP – distance	50km	2.153m	6.583m
NTRIP – latency	50km	0.155sec	0.474sec
Radio Link – distance	40km	1.456m	5.633m
Radio Link – latency	40km	0.131sec	0.507sec
NTRIP – distance	40km	1.856m	6.077m
NTRIP – latency	40km	0.167sec	0.547sec

It is recognised that the confidence range of latency time at each speed is different and that prior to measurement it was believed that the speed should have little effect on latency. However, when considering that the latency results, at each of the upper and lower confidence levels the difference across all is with one tenth of a second with the exception of NTRIP at 50km/hr.

The following figures display the absolute variance from the mean latency time of each speed and method to show the spread of variation and the 95% confidence levels.

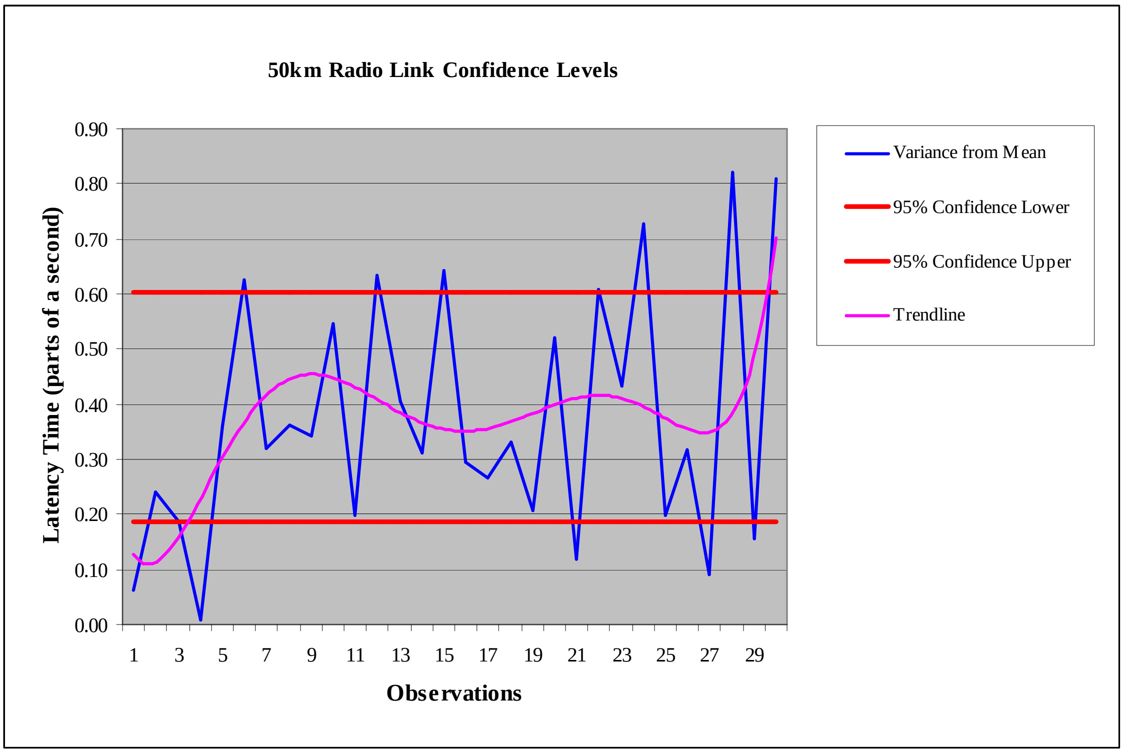

Figure 5.6 50km Radio Link confidence levels.

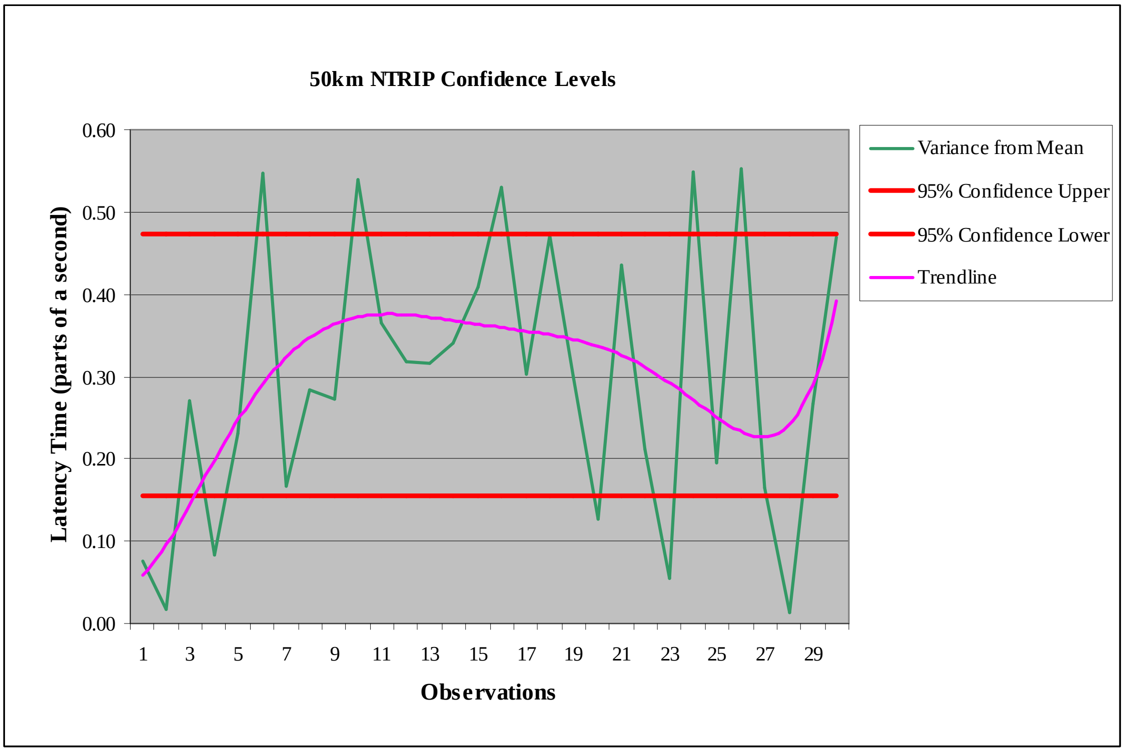

Figure 5.7 50km NTRIP confidence levels.

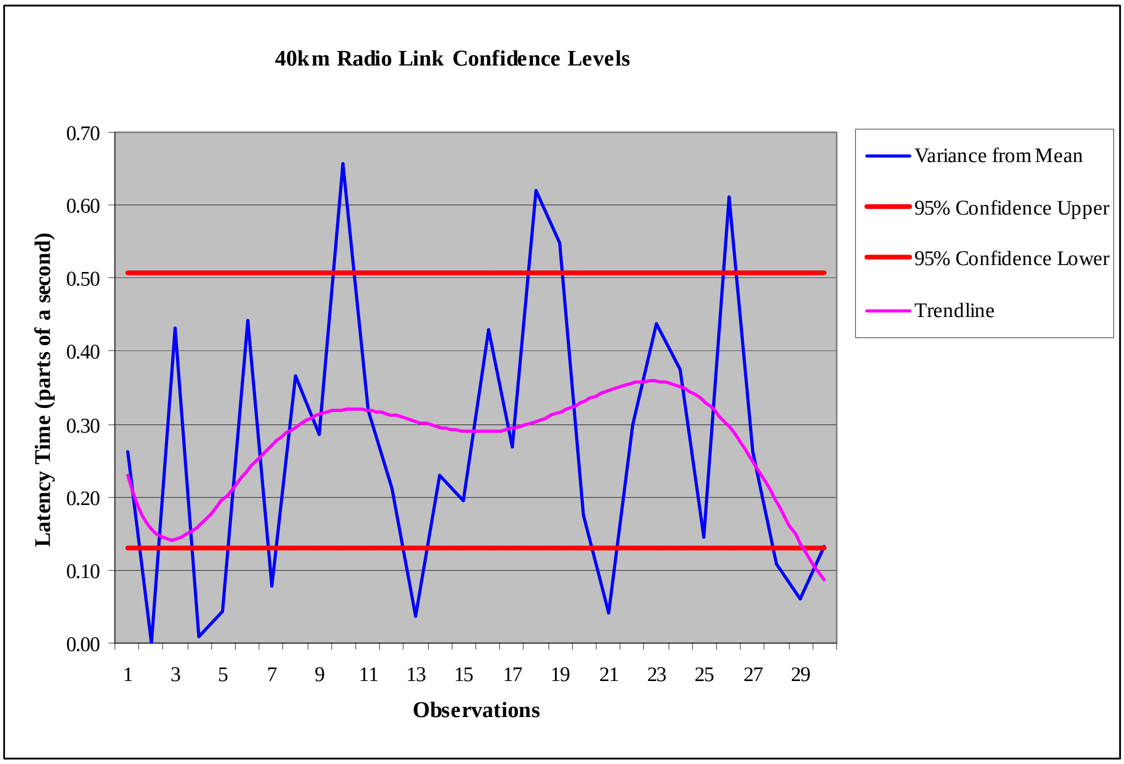

Figure 5.8 40km Radio Link confidence levels.

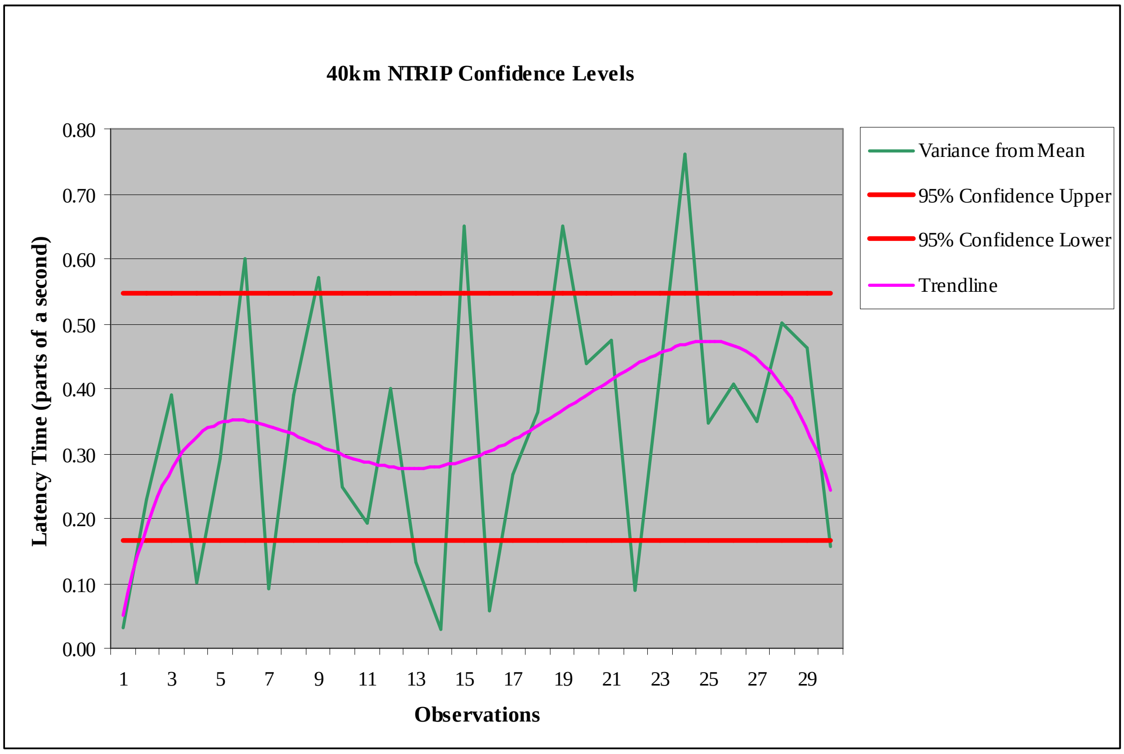

Figure 5.9 40km NTRIP confidence levels

The graphs above highlight that the latency time of a measured point is quite varied and random. It is possible that some of this randomness is due to the human input into the recording process but also the processing time for corrections to be computed for each measured point is also a factor. It was observed during the testing that if initialisation had been lost and then regained a minute or two prior to recording the processing is faster. On other occasions if not points had been stored for some time then the processing software can deteriorate and produce a greater latency time.

The above graphs also display a trendline which was implemented to show a general change in latency time for all measurements. In the 50km/hr tests there is a distinct rise in the trendline at the end of each testing session and in the 40km/hr tests there is a distinct decline in the trendline. The reason for this is not exactly known and could simply be a random anomaly.

6.0 Discussion

6.1 *Discussion*

The aim of this dissertation is to calculate and compare the noise and latency of GNSS correctional data transmitted from a Continuously Operating Reference Station (CORS) to a Roving receiver using traditional RTK radio link and NTRIP.

The noise affecting the transmission of GNSS correction data has been calculated by the analysing the dispersion (precision) of points measured using both Radio Link and NTRIP transmission methods as illustrated in Figures 4.1, 4.2 and 4.3. As discussed in **4.2.1**, the points measured using Radio Link at the one kilometre baseline was clearly more precise in their concentration than NTRIP; however as the baseline length increased the precision of Radio Link measurements deteriorated. The standard error calculated at the nine kilometre baseline length shows that the delta errors in Easting and Northing were similar for Radio Link and NTRIP.

The affect of noise on the transmission path for NTRIP plateaued out as baseline distances increased and therefore the spread of horizontal precisions became more stabilised with confidence intervals of between 2mm and 6mm maintained at the four and nine kilometre range. The ISCM, SP1 publication states that a ten kilometre range from a base station is typical for most Radio Link RTK surveys if accuracies are to be maintained, although some manufacturers state this range may be extended and this is where the use of NTRIP may find its niche.

Therefore, it can be reported that as baseline lengths increase, Radio Link measurements increase in error. Noise impacting the transmission of corrections is attributed to the increase in error and the subsequent downgrade of horizontal precisions the further Radio Link RTK surveys extend from the base.

From the evidence gathered it is clear that NTRIP data is less affected by signal noise the further the survey extends from the base. It is possible that the Radio Link correction signal becomes weaker the longer the distance it must travel and therefore becomes more susceptible to signal noise. Confidence intervals and standard deviations on the reported distances indicate that noise affecting the transmission of GNSS correction data remained more constant with NTRIP than with Radio Link.

The consistency of horizontal precisions at longer baseline lengths when using the NTRIP application could provide the opportunity for many surveyors to reconsider work strategies and equipment requirements. Utilising NTRIP could provide many benefits to surveying firms such as a reduction in operating costs, capital outlay, labour costs and project timelines. Most significantly, the process of using NTRIP would reduce survey crew sizes to one man operations and reduce the capital outlay for equipment because only a single GNSS receiver is required. There would also be a reduction for the need and therefore the purchase of large numbers of expensive robotic Total Stations. The only limitation is that substantial CORS networks only exist in some metropolitan areas and some states and not many rural locations. There is also an additional single cost of a subscription fee which is required to log into a CORS base.

The latency of transmission of GNSS correctional data using Radio Link and NTRIP was calculated by implementing a test that involved driving a car and measuring the distance from the start line to where the point was actually stored. This distance could then be converted to a latency time in relation to the speed the car was travelling.

As discussed in **4.3.1** and **4.3.2** the latency time of all measurements was less than one second. Similarly, the mean latency of all measurements was between 0.3 and 0.4 parts of a second. It is evident that these results differ significantly to those suggested by Webber et al (2004) and Dammalage et al (2009) whom both agree that there is a latency period of approximately three seconds when using of NTRIP.

The results have demonstrated that there have been significant improvements in technology since the release of the NTRIP application in 2004. The technological advancements of the modern internet and wireless connections stimulated by the insurgence of social networking are the reason why NTRIP is now on a par with Radio Link in terms of latency in receiving the GNSS corrections.

The results gained using NTRIP as a method of transmitting GNSS correctional data has demonstrated that this form of transmission method has the ability to meet not only the stated precisions of manufacturers but also the surveying standards required to perform many of our daily surveying tasks as set out in SP1.

6.2 *Further Research and Recommendations*

Considering the discovery of the consistent horizontal precisions of NTRIP data at the four kilometre and the nine kilometre baselines there is an opportunity to explore this further. How far can RTK surveys extend with the use of NTRIP? And do the precisions deteriorate further as these baselines extend beyond nine kilometres?

Future research into this area could provide the answers to the above questions and facilitate the launch of a dramatic expansion of RTK surveys. It could also mean that future networks of CORS base stations could be placed further apart, minimising set up costs with the discovery of expanded RTK NTRIP coverage.

The results on latency must include the consideration that measurements were taken which included human input (pressing the measure button at a certain time). While the speed component was controlled by cruise control settings, more accurate results could be gained by creating an electronic trigger that initiates the measuring process such as a sensor which is triggered by the weight of a car wheel passing across it, accompanied by a calculated offset to the position of the GNSS receiver. The method used by Inglis (2006) whereby a barcode reader was used to trigger the measuring process could be expanded to enhance the accuracy of the results presented.

While more accurate results may be possible, even with some latitude for human error the results indicate that latency times between Radio Link and NTRIP are negligible. With respect to the applications of RTK surveying these latency times would not cause any annoyance or limitation to the surveying task at hand.

7.0 Conclusion

The aim of this dissertation is to calculate and compare the noise and latency of GNSS correctional data transmitted from a Continuously Operating Reference Station (CORS) to a Roving receiver through an internet connection with the traditional method of radio link transmission.

It is evident from the results of this study that the deterioration of horizontal precisions of Radio Link and NTRIP data is strongly suspected to be caused be signal noise. The results indicate that Radio Link precisions decrease as baseline length increase, and that NTRIP precisions remain more constant across a variety of baseline lengths.

The affects of latency on the transmission of GNSS correctional data for Radio Link and NTRIP are difficult to accurately calculate due to the dynamic environment. This study can verify that latency times have decreased since the inception of NTRIP and that both methods of data transmission experience similar latency times with a maximum latency of less than one second. However, if the latency time can be quantified more accurately then it is therefore possible to correct for this in real time.

8.0 Appendices

A. *Project Specification*

University of Southern Queensland
FACULTY OF ENGINEERING AND SURVEYING

ENG4111 / 4112 Research Project
PROJECT SPECIFICATION

STUDENT :	Brian Penman
TOPIC :	CALCULATION AND COMPARISON OF THE NOISE AND LATENCY OF RTK OBSERVATIONS USING RADIO LINK AND NTRIP
SUPERVISOR :	Dr Peter Gibbings
ENROLMENT :	ENG4111 – S1, 2011; ENG4112 – S2, 2011
PROJECT AIM :	This project aim is to calculate the noise and latency of Global Navigation Satellite System (GNSS) correctional data transmitted from a Continually Operating Reference Station (CORS) to a roving receiver through an internet connection compared with the traditional method of radio link transmission. The project will identify the major factors that influence the noise and latency of internet transmitted data and the effect it will have on data quality.

PROGRAMME : Issued 5th April 2011

1. Research background information on GNSS data transmitted using the internet. Critically analyse the differences in transmission timings and noise that effect the quality of GNSS correctional data transmitted from a CORS base station to a roving receiver using conventional radio link and the internet.
2. Design a field research programme that will facilitate the assessment of the latency of data transmission using radio link and internet methods.

3. A statistical analysis will be conducted using data from the research programme to identify the effect that noise and timing have on the quality of transmitted data.
4. Evaluate the findings and make conclusions regarding the noise and latency of internet transmitted GNSS data.
5. Compare the findings of the field programme to the initial analysis. Evaluate and discuss these results.

6. Recommendations for 'best practice' will be made for the purpose of enhancing future surveying applications.

AGREED

Student________________________________ ____ Date_________________

Supervisor__________________________________ Date_________________

B. *Raw Static Observations and Calculations – Radio Link One Kilometre*

TSC2		Delta E	95% CI +	95% CI -	Delta N	95% CI +	95% CI -	TSC2 Vector
511945.796	7043909.199	-0.001	0.0015	-0.0015	0.002	0.0015	-0.0015	0.002
511945.795	7043909.199	0.000	0.0015	-0.0015	0.002	0.0015	-0.0015	0.002
511945.795	7043909.198	0.000	0.0015	-0.0015	0.003	0.0015	-0.0015	0.003
511945.795	7043909.198	0.000	0.0015	-0.0015	0.003	0.0015	-0.0015	0.003
511945.796	7043909.201	-0.001	0.0015	-0.0015	0.000	0.0015	-0.0015	0.001
511945.796	7043909.202	-0.001	0.0015	-0.0015	-0.001	0.0015	-0.0015	0.001
511945.797	7043909.200	-0.002	0.0015	-0.0015	0.001	0.0015	-0.0015	0.002
511945.797	7043909.200	-0.002	0.0015	-0.0015	0.001	0.0015	-0.0015	0.002
511945.797	7043909.201	-0.002	0.0015	-0.0015	0.000	0.0015	-0.0015	0.002
511945.797	7043909.199	-0.002	0.0015	-0.0015	0.002	0.0015	-0.0015	0.003
511945.795	7043909.199	0.000	0.0015	-0.0015	0.002	0.0015	-0.0015	0.002
511945.794	7043909.200	0.001	0.0015	-0.0015	0.001	0.0015	-0.0015	0.001
511945.795	7043909.201	0.000	0.0015	-0.0015	0.000	0.0015	-0.0015	0.000
511945.795	7043909.201	0.000	0.0015	-0.0015	0.000	0.0015	-0.0015	0.000
511945.794	7043909.200	0.001	0.0015	-0.0015	0.001	0.0015	-0.0015	0.001
511945.794	7043909.200	0.001	0.0015	-0.0015	0.001	0.0015	-0.0015	0.001
511945.793	7043909.203	0.002	0.0015	-0.0015	-0.002	0.0015	-0.0015	0.003
511945.795	7043909.201	0.000	0.0015	-0.0015	0.000	0.0015	-0.0015	0.000
511945.795	7043909.204	0.000	0.0015	-0.0015	-0.003	0.0015	-0.0015	0.003
511945.795	7043909.202	0.000	0.0015	-0.0015	-0.001	0.0015	-0.0015	0.001
511945.796	7043909.203	-0.001	0.0015	-0.0015	-0.002	0.0015	-0.0015	0.002
511945.795	7043909.203	0.000	0.0015	-0.0015	-0.002	0.0015	-0.0015	0.002
511945.792	7043909.203	0.003	0.0015	-0.0015	-0.002	0.0015	-0.0015	0.004
511945.792	7043909.201	0.003	0.0015	-0.0015	0.000	0.0015	-0.0015	0.003
511945.794	7043909.203	0.001	0.0015	-0.0015	-0.002	0.0015	-0.0015	0.002
511945.794	7043909.204	0.001	0.0015	-0.0015	-0.003	0.0015	-0.0015	0.003
511945.793	7043909.202	0.002	0.0015	-0.0015	-0.001	0.0015	-0.0015	0.002
511945.794	7043909.202	0.001	0.0015	-0.0015	-0.001	0.0015	-0.0015	0.001
511945.794	7043909.200	0.001	0.0015	-0.0015	0.001	0.0015	-0.0015	0.001
511945.795	7043909.201	0.000	0.0015	-0.0015	0.000	0.0015	-0.0015	0.000
511945.797	7043909.216	0.000		Known Value			Mean	0.002
511945.795	7043909.201	0.002		Mean TSC2	0.015		Std Dev	0.001
511945.794	7043909.199	0.003		Mean TSC3	0.017		95% CI	0.002
0.003	0.003	95% CI for coords						
0.001341212	0.001681543	Std Dev						

C. *Raw Static Observations and Calculations – NTRIP One Kilometre*

TSC3		Delta E	95% CI +	95% CI -	Delta N	95% CI +	95% CI -	TSC3 Vector
511945.796	7043909.196	-0.002	0.0015	-0.0015	0.003	0.0020	-0.0020	0.004
511945.794	7043909.195	0.000	0.0015	-0.0015	0.004	0.0020	-0.0020	0.004
511945.794	7043909.198	0.000	0.0015	-0.0015	0.001	0.0020	-0.0020	0.001
511945.794	7043909.197	0.000	0.0015	-0.0015	0.002	0.0020	-0.0020	0.002
511945.793	7043909.197	0.001	0.0015	-0.0015	0.002	0.0020	-0.0020	0.002
511945.793	7043909.197	0.001	0.0015	-0.0015	0.002	0.0020	-0.0020	0.002
511945.793	7043909.197	0.001	0.0015	-0.0015	0.002	0.0020	-0.0020	0.002
511945.793	7043909.198	0.001	0.0015	-0.0015	0.001	0.0020	-0.0020	0.001
511945.792	7043909.197	0.002	0.0015	-0.0015	0.002	0.0020	-0.0020	0.003
511945.791	7043909.199	0.003	0.0015	-0.0015	0.000	0.0020	-0.0020	0.003
511945.793	7043909.198	0.001	0.0015	-0.0015	0.001	0.0020	-0.0020	0.001
511945.793	7043909.199	0.001	0.0015	-0.0015	0.000	0.0020	-0.0020	0.001
511945.794	7043909.199	0.000	0.0015	-0.0015	0.000	0.0020	-0.0020	0.000
511945.794	7043909.200	0.000	0.0015	-0.0015	-0.001	0.0020	-0.0020	0.001
511945.795	7043909.201	-0.001	0.0015	-0.0015	-0.002	0.0020	-0.0020	0.002
511945.796	7043909.199	-0.002	0.0015	-0.0015	0.000	0.0020	-0.0020	0.002
511945.797	7043909.202	-0.003	0.0015	-0.0015	-0.003	0.0020	-0.0020	0.004
511945.796	7043909.204	-0.002	0.0015	-0.0015	-0.005	0.0020	-0.0020	0.005
511945.797	7043909.203	-0.003	0.0015	-0.0015	-0.004	0.0020	-0.0020	0.005
511945.796	7043909.201	-0.002	0.0015	-0.0015	-0.002	0.0020	-0.0020	0.003
511945.796	7043909.200	-0.002	0.0015	-0.0015	-0.001	0.0020	-0.0020	0.002
511945.796	7043909.200	-0.002	0.0015	-0.0015	-0.001	0.0020	-0.0020	0.002
511945.795	7043909.198	-0.001	0.0015	-0.0015	0.001	0.0020	-0.0020	0.001
511945.795	7043909.199	-0.001	0.0015	-0.0015	0.000	0.0020	-0.0020	0.001
511945.794	7043909.201	0.000	0.0015	-0.0015	-0.002	0.0020	-0.0020	0.002
511945.794	7043909.202	0.000	0.0015	-0.0015	-0.003	0.0020	-0.0020	0.003
511945.793	7043909.202	0.001	0.0015	-0.0015	-0.003	0.0020	-0.0020	0.003
511945.795	7043909.199	-0.001	0.0015	-0.0015	0.000	0.0020	-0.0020	0.001
511945.794	7043909.199	0.000	0.0015	-0.0015	0.000	0.0020	-0.0020	0.000
511945.796	7043909.198	-0.002	0.0015	-0.0015	0.001	0.0020	-0.0020	0.002
0.003	0.004	95% CI for coords					Mean	0.002
0.0014994	0.0021348	Std Dev					Std Dev	0.001
							95% CI	0.002

D. *Raw Static Observations and Calculations – Radio Link Four Kilometres*

TSC2		Delta E	95% CI +	95% CI -	Delta N	95% CI +	95% CI -	TSC2 Vector
512938.075	7046656.083	0.0030	0.0015	-0.0015	0.001	0.0025	-0.0025	0.003
512938.076	7046656.082	0.0020	0.0015	-0.0015	0.002	0.0025	-0.0025	0.003
512938.078	7046656.082	0.0000	0.0015	-0.0015	0.002	0.0025	-0.0025	0.002
512938.078	7046656.085	0.0000	0.0015	-0.0015	-0.001	0.0025	-0.0025	0.001
512938.079	7046656.086	-0.0010	0.0015	-0.0015	-0.002	0.0025	-0.0025	0.002
512938.078	7046656.085	0.0000	0.0015	-0.0015	-0.001	0.0025	-0.0025	0.001
512938.077	7046656.086	0.0010	0.0015	-0.0015	-0.002	0.0025	-0.0025	0.002
512938.076	7046656.089	0.0020	0.0015	-0.0015	-0.005	0.0025	-0.0025	0.005
512938.077	7046656.089	0.0010	0.0015	-0.0015	-0.005	0.0025	-0.0025	0.005
512938.076	7046656.090	0.0020	0.0015	-0.0015	-0.006	0.0025	-0.0025	0.006
512938.077	7046656.086	0.0010	0.0015	-0.0015	-0.002	0.0025	-0.0025	0.002
512938.078	7046656.083	0.0000	0.0015	-0.0015	0.001	0.0025	-0.0025	0.001
512938.079	7046656.085	-0.0010	0.0015	-0.0015	-0.001	0.0025	-0.0025	0.001
512938.078	7046656.086	0.0000	0.0015	-0.0015	-0.002	0.0025	-0.0025	0.002
512938.077	7046656.085	0.0010	0.0015	-0.0015	-0.001	0.0025	-0.0025	0.001
512938.078	7046656.085	0.0000	0.0015	-0.0015	-0.001	0.0025	-0.0025	0.001
512938.079	7046656.083	-0.0010	0.0015	-0.0015	0.001	0.0025	-0.0025	0.001
512938.078	7046656.083	0.0000	0.0015	-0.0015	0.001	0.0025	-0.0025	0.001
512938.078	7046656.082	0.0000	0.0015	-0.0015	0.002	0.0025	-0.0025	0.002
512938.077	7046656.081	0.0010	0.0015	-0.0015	0.003	0.0025	-0.0025	0.003
512938.078	7046656.081	0.0000	0.0015	-0.0015	0.003	0.0025	-0.0025	0.003
512938.079	7046656.081	-0.0010	0.0015	-0.0015	0.003	0.0025	-0.0025	0.003
512938.081	7046656.081	-0.0030	0.0015	-0.0015	0.003	0.0025	-0.0025	0.004
512938.077	7046656.081	0.0010	0.0015	-0.0015	0.003	0.0025	-0.0025	0.003
512938.078	7046656.083	0.0000	0.0015	-0.0015	0.001	0.0025	-0.0025	0.001
512938.078	7046656.082	0.0000	0.0015	-0.0015	0.002	0.0025	-0.0025	0.002
512938.077	7046656.082	0.0010	0.0015	-0.0015	0.002	0.0025	-0.0025	0.002
512938.080	7046656.084	-0.0020	0.0015	-0.0015	0.000	0.0025	-0.0025	0.002
512938.074	7046656.084	0.0040	0.0015	-0.0015	0.000	0.0025	-0.0025	0.004
512938.074	7046656.084	0.0040	0.0015	-0.0015	0.000	0.0025	-0.0025	0.004

512938.081	7046656.099	0.0000		Known Value			Mean	0.003
512938.078	7046656.084	0.0030		Mean TSC2	0.015		Std Dev	0.001
512938.082	7046656.088	-0.0010		Mean TSC3	0.011		95% CI	0.002
0.00154808	0.00247028	TSC2 Std Dev						
0.003	0.005	95% CI						

E. *Raw Static Observations and Calculations – NTRIP Four Kilometres*

TSC3		Delta E	95% CI +	95% CI -	Delta N	95% CI +	95% CI -	TSC3 Vector
512938.075	7046656.089	0.007	0.0030	-0.0030	-0.001	0.0035	-0.0035	0.0071
512938.076	7046656.088	0.006	0.0030	-0.0030	0.000	0.0035	-0.0035	0.0060
512938.077	7046656.086	0.005	0.0030	-0.0030	0.002	0.0035	-0.0035	0.0054
512938.079	7046656.086	0.003	0.0030	-0.0030	0.002	0.0035	-0.0035	0.0036
512938.078	7046656.086	0.004	0.0030	-0.0030	0.002	0.0035	-0.0035	0.0045
512938.083	7046656.086	-0.001	0.0030	-0.0030	0.002	0.0035	-0.0035	0.0022
512938.085	7046656.086	-0.003	0.0030	-0.0030	0.002	0.0035	-0.0035	0.0036
512938.087	7046656.085	-0.005	0.0030	-0.0030	0.003	0.0035	-0.0035	0.0058
512938.087	7046656.085	-0.005	0.0030	-0.0030	0.003	0.0035	-0.0035	0.0058
512938.086	7046656.085	-0.004	0.0030	-0.0030	0.003	0.0035	-0.0035	0.0050
512938.086	7046656.086	-0.004	0.0030	-0.0030	0.002	0.0035	-0.0035	0.0045
512938.086	7046656.088	-0.004	0.0030	-0.0030	0.000	0.0035	-0.0035	0.0040
512938.086	7046656.090	-0.004	0.0030	-0.0030	-0.002	0.0035	-0.0035	0.0045
512938.086	7046656.094	-0.004	0.0030	-0.0030	-0.006	0.0035	-0.0035	0.0072
512938.083	7046656.094	-0.001	0.0030	-0.0030	-0.006	0.0035	-0.0035	0.0061
512938.082	7046656.094	0.000	0.0030	-0.0030	-0.006	0.0035	-0.0035	0.0060
512938.080	7046656.095	0.002	0.0030	-0.0030	-0.007	0.0035	-0.0035	0.0073
512938.080	7046656.094	0.002	0.0030	-0.0030	-0.006	0.0035	-0.0035	0.0063
512938.081	7046656.090	0.001	0.0030	-0.0030	-0.002	0.0035	-0.0035	0.0022
512938.082	7046656.089	0.000	0.0030	-0.0030	-0.001	0.0035	-0.0035	0.0010
512938.082	7046656.088	0.000	0.0030	-0.0030	0.000	0.0035	-0.0035	0.0000
512938.083	7046656.086	-0.001	0.0030	-0.0030	0.002	0.0035	-0.0035	0.0022
512938.081	7046656.086	0.001	0.0030	-0.0030	0.002	0.0035	-0.0035	0.0022
512938.081	7046656.084	0.001	0.0030	-0.0030	0.004	0.0035	-0.0035	0.0041
512938.082	7046656.084	0.000	0.0030	-0.0030	0.004	0.0035	-0.0035	0.0040
512938.084	7046656.085	-0.002	0.0030	-0.0030	0.003	0.0035	-0.0035	0.0036
512938.084	7046656.084	-0.002	0.0030	-0.0030	0.004	0.0035	-0.0035	0.0045
512938.083	7046656.084	-0.001	0.0030	-0.0030	0.004	0.0035	-0.0035	0.0041
512938.083	7046656.086	-0.001	0.0030	-0.0030	0.002	0.0035	-0.0035	0.0022
512938.084	7046656.088	-0.002	0.0030	-0.0030	0.000	0.0035	-0.0035	0.0020
0.00320129	0.00340537	TSC3 Std Dev					Mean	0.004
0.006	0.007	95% CI					Std Dev	0.002
							95% CI	0.004

F. *Raw Static Observations and Calculations – Radio Link Nine Kilometres*

TSC2		Delta E	95% CI +	95% CI -	Delta N	95% CI +	95% CI -	TSC2 Vector
508006.495	7051673.858	-0.004	0.0030	-0.0030	-0.001	0.0035	-0.0035	0.004
508006.498	7051673.857	-0.007	0.0030	-0.0030	0.000	0.0035	-0.0035	0.007
508006.497	7051673.855	-0.006	0.0030	-0.0030	0.002	0.0035	-0.0035	0.006
508006.492	7051673.854	-0.001	0.0030	-0.0030	0.003	0.0035	-0.0035	0.003
508006.492	7051673.854	-0.001	0.0030	-0.0030	0.003	0.0035	-0.0035	0.003
508006.489	7051673.854	0.002	0.0030	-0.0030	0.003	0.0035	-0.0035	0.004
508006.493	7051673.857	-0.002	0.0030	-0.0030	0.000	0.0035	-0.0035	0.002
508006.492	7051673.852	-0.001	0.0030	-0.0030	0.005	0.0035	-0.0035	0.005
508006.490	7051673.849	0.001	0.0030	-0.0030	0.008	0.0035	-0.0035	0.008
508006.493	7051673.852	-0.002	0.0030	-0.0030	0.005	0.0035	-0.0035	0.005
508006.492	7051673.859	-0.001	0.0030	-0.0030	-0.002	0.0035	-0.0035	0.002
508006.490	7051673.860	0.001	0.0030	-0.0030	-0.003	0.0035	-0.0035	0.003
508006.491	7051673.862	0.000	0.0030	-0.0030	-0.005	0.0035	-0.0035	0.005
508006.494	7051673.859	-0.003	0.0030	-0.0030	-0.002	0.0035	-0.0035	0.004
508006.492	7051673.858	-0.001	0.0030	-0.0030	-0.001	0.0035	-0.0035	0.001
508006.493	7051673.856	-0.002	0.0030	-0.0030	0.001	0.0035	-0.0035	0.002
508006.491	7051673.858	0.000	0.0030	-0.0030	-0.001	0.0035	-0.0035	0.001
508006.489	7051673.860	0.002	0.0030	-0.0030	-0.003	0.0035	-0.0035	0.004
508006.491	7051673.857	0.000	0.0030	-0.0030	0.000	0.0035	-0.0035	0.000
508006.495	7051673.860	-0.004	0.0030	-0.0030	-0.003	0.0035	-0.0035	0.005
508006.492	7051673.860	-0.001	0.0030	-0.0030	-0.003	0.0035	-0.0035	0.003
508006.494	7051673.859	-0.003	0.0030	-0.0030	-0.002	0.0035	-0.0035	0.004
508006.492	7051673.858	-0.001	0.0030	-0.0030	-0.001	0.0035	-0.0035	0.001
508006.487	7051673.859	0.004	0.0030	-0.0030	-0.002	0.0035	-0.0035	0.004
508006.488	7051673.860	0.003	0.0030	-0.0030	-0.003	0.0035	-0.0035	0.004
508006.488	7051673.862	0.003	0.0030	-0.0030	-0.005	0.0035	-0.0035	0.006
508006.486	7051673.858	0.005	0.0030	-0.0030	-0.001	0.0035	-0.0035	0.005
508006.487	7051673.857	0.004	0.0030	-0.0030	0.000	0.0035	-0.0035	0.004
508006.484	7051673.853	0.007	0.0030	-0.0030	0.004	0.0035	-0.0035	0.008
508006.487	7051673.848	0.004	0.0030	-0.0030	0.009	0.0035	-0.0035	0.010
508006.487	7051673.874	0.000		Known Value			Mean	0.004
508006.491	7051673.857	-0.004		TSC2 Mean	0.017		Std Dev	0.002
508006.493	7051673.853	-0.006		TSC3 Mean	0.021		95% CI	0.004
0.006	0.007	95% CI for coords						
0.00323487	0.00351434	Std Dev						

G. *Raw Static Observations and Calculations – NTRIP Nine Kilometres*

TSC3		Delta E	95% CI +	95% CI -	Delta N	95% CI +	95% CI -	TSC3 Vector
508006.494	7051673.857	-0.001	0.0030	-0.0030	-0.004	0.0035	-0.0035	0.004
508006.498	7051673.862	-0.005	0.0030	-0.0030	-0.009	0.0035	-0.0035	0.010
508006.495	7051673.855	-0.002	0.0030	-0.0030	-0.002	0.0035	-0.0035	0.003
508006.493	7051673.856	0.000	0.0030	-0.0030	-0.003	0.0035	-0.0035	0.003
508006.491	7051673.857	0.002	0.0030	-0.0030	-0.004	0.0035	-0.0035	0.004
508006.491	7051673.859	0.002	0.0030	-0.0030	-0.006	0.0035	-0.0035	0.006
508006.489	7051673.859	0.004	0.0030	-0.0030	-0.006	0.0035	-0.0035	0.007
508006.490	7051673.854	0.003	0.0030	-0.0030	-0.001	0.0035	-0.0035	0.003
508006.486	7051673.855	0.007	0.0030	-0.0030	-0.002	0.0035	-0.0035	0.007
508006.490	7051673.855	0.003	0.0030	-0.0030	-0.002	0.0035	-0.0035	0.004
508006.491	7051673.853	0.002	0.0030	-0.0030	0.000	0.0035	-0.0035	0.002
508006.491	7051673.853	0.002	0.0030	-0.0030	0.000	0.0035	-0.0035	0.002
508006.492	7051673.856	0.001	0.0030	-0.0030	-0.003	0.0035	-0.0035	0.003
508006.496	7051673.853	-0.003	0.0030	-0.0030	0.000	0.0035	-0.0035	0.003
508006.490	7051673.851	0.003	0.0030	-0.0030	0.002	0.0035	-0.0035	0.004
508006.490	7051673.847	0.003	0.0030	-0.0030	0.006	0.0035	-0.0035	0.007
508006.494	7051673.852	-0.001	0.0030	-0.0030	0.001	0.0035	-0.0035	0.001
508006.494	7051673.851	-0.001	0.0030	-0.0030	0.002	0.0035	-0.0035	0.002
508006.496	7051673.853	-0.003	0.0030	-0.0030	0.000	0.0035	-0.0035	0.003
508006.493	7051673.849	0.000	0.0030	-0.0030	0.004	0.0035	-0.0035	0.004
508006.494	7051673.848	-0.001	0.0030	-0.0030	0.005	0.0035	-0.0035	0.005
508006.494	7051673.848	-0.001	0.0030	-0.0030	0.005	0.0035	-0.0035	0.005
508006.493	7051673.850	0.000	0.0030	-0.0030	0.003	0.0035	-0.0035	0.003
508006.497	7051673.852	-0.004	0.0030	-0.0030	0.001	0.0035	-0.0035	0.004
508006.495	7051673.852	-0.002	0.0030	-0.0030	0.001	0.0035	-0.0035	0.002
508006.495	7051673.852	-0.002	0.0030	-0.0030	0.001	0.0035	-0.0035	0.002
508006.493	7051673.851	0.000	0.0030	-0.0030	0.002	0.0035	-0.0035	0.002
508006.490	7051673.851	0.003	0.0030	-0.0030	0.002	0.0035	-0.0035	0.004
508006.497	7051673.854	-0.004	0.0030	-0.0030	-0.001	0.0035	-0.0035	0.004
508006.497	7051673.855	-0.004	0.0030	-0.0030	-0.002	0.0035	-0.0035	0.004
0.006	0.007	95% CI for coords					Mean	0.004
0.00284645	0.00346742	Std Dev					Std Dev	0.002
							95% CI	0.004

H. *Raw Data 50km/hr Latency Test – Conversion Metres to Time*

Radio 50km		NTRIP 50km	
Dist	**Latency**	**Dist**	**Latency**
6.353	0.457	3.314	0.239
8.058	0.580	7.437	0.535
3.386	0.244	3.945	0.284
3.070	0.221	1.114	0.080
0.811	0.058	1.234	0.089
8.674	0.625	7.601	0.547
4.461	0.321	2.310	0.166
5.015	0.361	3.931	0.283
4.754	0.342	3.796	0.273
7.604	0.547	7.505	0.540
2.763	0.199	5.079	0.366
8.809	0.634	4.410	0.318
5.637	0.406	4.380	0.315
4.336	0.312	4.721	0.340
8.915	0.642	5.681	0.409
4.082	0.294	7.358	0.530
3.713	0.267	4.214	0.303
4.609	0.332	6.558	0.472
2.887	0.208	4.185	0.301
7.218	0.520	1.768	0.127
1.667	0.120	6.033	0.434
8.459	0.609	2.941	0.212
6.009	0.433	0.752	0.054
10.111	0.728	7.632	0.550
2.768	0.199	2.705	0.195
4.394	0.316	7.672	0.552
1.261	0.091	2.281	0.164
11.413	0.822	0.189	0.014
2.146	0.155	3.698	0.266
11.237	0.809	6.524	0.470
Sum	11.853		9.430
Mean	0.395		0.314
Max	0.822		0.552
Min	0.058		0.014

I. *Raw Data 40km/hr Latency Test – Conversion Metres to Time*

Radio 40km		NTRIP 40km	
Dist	**Latency**	**Dist**	**Latency**
6.472	0.582	3.620	0.326
7.363	0.663	5.905	0.531
5.203	0.468	4.654	0.419
2.224	0.200	3.277	0.295
3.684	0.332	0.981	0.088
4.905	0.441	6.675	0.601
0.857	0.077	1.004	0.090
4.076	0.367	4.338	0.390
3.171	0.285	6.346	0.571
7.295	0.656	2.770	0.249
3.547	0.319	2.149	0.193
2.355	0.212	4.448	0.400
0.415	0.037	1.484	0.134
2.555	0.230	0.324	0.029
2.171	0.195	7.233	0.651
4.779	0.430	0.652	0.059
2.976	0.268	2.973	0.268
6.892	0.620	4.050	0.364
6.092	0.548	7.230	0.651
1.961	0.176	4.875	0.439
0.449	0.040	5.286	0.476
3.317	0.299	0.998	0.090
4.860	0.437	4.676	0.421
4.175	0.376	8.459	0.761
1.616	0.145	3.866	0.348
6.791	0.611	4.530	0.408
2.923	0.263	3.878	0.349
1.196	0.108	5.571	0.501
0.684	0.062	5.132	0.462
1.480	0.133	1.736	0.156
Sum	9.583		10.720
Mean	0.319		0.357
Max	0.663		0.761
Min	0.037		0.029

J. *CORS Base Coordinates*

Project information		Coordinate System	
Name:	E:\BP\THESIS\TSC3 Raw 25.06.11.vce	Name:	Map Grid of Australia (GDA)
Size:	445 KB	Datum:	ITRF
Modified:	7/23/2011 9:49:30 AM	Zone:	Zone 56
Reference number:		Geoid:	AUSGEOID98 (Australia)
Description:		Vertical datum:	

Additional Coordinate System Details

Local Site Settings			
Project latitude:	?	Ground scale factor:	1
Project longitude:	?	False northing offset:	0.000 m
Project height:	0.000 m	False easting offset:	0.000 m

Point List

ID	Easting (Meter)	Northing (Meter)	Elevation (Meter)	Feature Code
CONICS01	512138.150	7043184.970	18.892	CORS Base

7/23/2011 10:12:22 AM	E:\BP\THESIS\TSC3 Raw 25.06.11.vce	Trimble Business Center

K. *Stake Out Report Radio Link*

Job name:	110625BPTSC2	Trimble Survey Controller version:	12.46
Creation date:	2011-06-25	Distance/Coord units:	Meters
Start date for reported points:	25 Jun 2011	End date for reported points:	25 Jun 2011

25 Jun 2011

Point Stakeout

Design Name	Code	Design E	Design N	Design Z	Staked Z	Cut/Fill	ΔE	ΔN
PSM112457	CHKA	512821.270	7042896.437	3.209	3.154	0.055	-0.008	-0.026
PSM152206	CHKB	511812.269	7043872.607	3.013	3.017	-0.004	-0.030	0.007
PSM152206	CHKB	511812.269	7043872.607	3.013	2.985	0.028	-0.031	0.010

L. *Stake Out Report NTRIP*

Job name:	110625BPTSC3	Trimble General Survey version:	1.50
Creation date:	2011-06-25	Distance/Coord units:	Meters
Start date for reported points:	25 Jun 2011	End date for reported points:	25 Jun 2011

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25 Jun 2011

Point Stakeout								
Design Name	**Code**	**Design E**	**Design N**	**Design Z**	**Staked Z**	**Cut/Fill**	**ΔE**	**ΔN**
PSM112457	CHKA	512821.270	7042896.437	3.209	3.165	0.044	-0.011	-0.017
PSM152206	CHKB	511812.269	7043872.607	3.013	3.004	0.009	-0.029	0.019
PSM152206	CHKB	511812.269	7043872.607	3.013	2.989	0.024	-0.027	0.012

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