Delivery of Networked GPS Corrections for Machinery Guidance

J.C. Millner[1], H.J. Asmussen[1] and R. Andreola[2], [1] Spatial Information Infrastructure, Department of Sustainability and Environment, Melbourne, Vic., [2] School of Mathematical & Geospatial Science, RMIT University, Melbourne, Vic.

Abstract: The Department of Sustainability and Environment (DSE) in Victoria has developed a Global Positioning System (GPS) Continually Operating Reference Station (CORS) infrastructure called GPSnet™. Recently GPSnet has been enhanced with two real-time GPS correction services: VICpos and MELBpos. These services supply Differential GPS (DGPS) and Networked Real-Time Kinematic (NRTK) corrections that are suitable for applications such as machine guidance. VICpos DGPS corrections deliver sub-metre results Victoria wide, while MELBpos NRTK is a high accuracy centimetre positioning service for the Melbourne and environs. Real-time data streams are made available over the Internet for access by fixed or mobile devices.

This paper briefly describes GPSnet CORS architecture which is designed to provide robust NRTK positioning services. Current plans to construct additional GPSnet infrastructure to improve the high accuracy service delivery in regional areas of Victoria is discussed. A novel methodology for obtaining high accuracy positioning from the Internet as an alternative to using a mobile phone connection in rural areas is also presented.

Key Words: MELBpos, VICpos, GPSnet, Precision Agriculture, NRTK, Virtual Base Station, GNSS Internet Radio

INTRODUCTION

Spatial Information Infrastructure (SII), an agency within the Department of Sustainability and Environment (DSE) in Victoria, has been involved with the development of Global Positioning System (GPS) Continually Operating Reference Stations (CORS) infrastructure called *GPSnet™* [1] since the mid 1990's. Initially GPSnet was designed for the more traditional purposes of surveying, mapping and geodetic control. However, the vast improvement in positional accuracy obtained from Differential (DGPS) and Real-Time Kinematic (RTK) services has lead to a proliferation of new GPS applications that now demand instantaneous, robust, high accuracy results.

To meet the stringent requirements of emerging applications such as precise machine guidance, GPSnet has been enhanced to stream real-time correction data over the Internet (Millner *et al.* 2004). Two services: VICpos the DGPS sub-metre positioning service available anywhere in Victoria and MELBpos a high accuracy Networked Real-Time Kinematic (NRTK) service which is valid over Melbourne and environs, offer a mix of data streams for a growing variety of uses. Generally real-time users access the Internet positioning services from a mobile phone with General Packet Radio Service (GPRS) Internet data services installed. However, a mobile Internet connection from the GPRS network is not

[1] GPSnet™ is registered in and by the State of Victoria as a business name (from April 2000 in 3-year intervals) and is also a registered trademark (from 17 January 2000 in ten-year intervals).

always a practical solution, particularly in rural and remote areas where mobile coverage is often sparse.

This paper presents the methodology for setting up a local radio re-broadcast from a fixed line Internet connection where the mobile phone coverage is limited or non-existent. The investigation focuses primarily on a Very Small Aperture Terminal (VSAT) geostationary satellite service as the fixed Internet connection in combination with a local Ultra High Frequency (UHF) or Very High Frequency (VHF) radio re-broadcast. A brief introduction to the CORS architecture required to generate NRTK corrections and the current plans to extend the high accuracy CORS network in Victoria's western districts will also be discussed.

CONTINUALLY OPERATING REFERENCE STATION (CORS) NETWORKS

CORS networks were first established in the early 1990's by the National Geodetic Survey to cover the United States and its territories. CORS networks have rapidly proliferated throughout the world by the virtue of a universal attraction for reliable and authoritative position information.

The Australian Regional Geodetic Network (ARGN) is a network of 15 sites that define the Geocentric Datum of Australia (GDA), the fundamental framework for all national spatial information. Cooperative jurisdictional sub-networks supplement the ARGN: GPSnet in Victoria, SunPoz in Queensland and SYDNet in New South Wales. The vast size of the Australian continent creates a huge economic and technical challenge for national real-time centimetre positioning services based on CORS networks. These challenges need to be addressed however as there is increasing demand from many user groups to provide national real-time coverage from CORS infrastructure. The eventual aim of Victoria's cooperative GPSnet infrastructure is to provide real-time centimetre solutions state wide.

ADVANTAGES OF CORS NETWORK INFRASTRUCTURE

The most apparent advantage of CORS infrastructure is that it saves a user time, effort and money by eliminating the need to purchase, operate and maintain their own private reference station equipment. Denham *et al*. (2006) describes in detail the benefits offered to precision agriculture from properly configured CORS networks such as GPSnet. Properly configured CORS networks can achieve greater accuracy over larger coverage areas compared to a single private reference station: *pass-to-pass and year-to-year*.

Not so apparent is the computing complexity required to allow the same pass-to-pass and year-to-year accuracy to be constant from farm-to-farm, nation wide. GPSnet coordinates are computed relative to the nation's fundamental CORS GPS network—the ARGN (Ramm *et al.* 2004). Undistorted national coordinates permit generation of NRTK solutions at 1-centimetre horizontal accuracy. For example homogenous results based on national coordinates are essential for machinery contactors that rely on consistent correction data around the whole country.

One difficulty with the existing Australian CORS infrastructure is the density of spacing required to achieve centimetre positions in real-time. The question of how to increase accuracy from infrequently spaced CORS sites is an active topic for our leading geodetic researchers at the Cooperative Research Centre for Spatial Information (CRS-SI). In addition, Hale *et al*. (2006) introduces the topical concept of a CORS management model that will put together arrangements such that CORS networks in Australia can be expanded in a unified and sustainable way to optimise use and maximise benefits.

GPSNET ARCHITECTURE

GPSnet architecture has evolved in development since 1995. Given that GPS correction services can provide high accuracy, the main issues relating to the architecture development are not related to accuracy but to robustness measured through performance, integrity and continuity. Architecture specifications include performance requirements for computing hardware, software and communication equipment and the management tools necessary to support continuous GPSnet operations. For details see Vicmap Position – GPSnet Product Description: www.land.vic.gov.au

GPSNET REFERENCE STATION SITES AND TELECOMMUNICATIONS

GPSnet sites require high-grade geodetic receivers, firmly mounted and housed securely with an unimpeded view of the sky. Sites are carefully selected to avoid signal multipath and spurious radio frequency interference. Backup power with surge protection and data storage is included. Equipment is now being progressively upgraded to be compatible with Global Navigation Satellite System (GNSS) such as modernised GPS (L_2C and L_5), GLONASS (Russian Federation) and Galileo (European Satellite Navigation System) signals.

Generally each locality has different telecommunications for remote operation and data transfer. The preferred option is a high bandwidth, low latency Digital Subscriber Lines (DSL ADSL, Wireless, or Satellite) that permits direct TCP/IP configuration and remote management. Data is streamed in real-time to a central processing centre over a secure Virtual Private Network (VPN). The VPN is flexible enough to incorporate hosted connectivity and facility management. For example additional cooperative sites can be added and managed under a GPSnet Host Agreement (see www.land.vic.gov.au/Gpsnet) regardless of their location with communication and facility costs kept to a minimum.

CENTRALISED PROCESSING CENTRE

The centralised server cluster processing facility was designed by engineers from Trimble Navigation, currently located at Barwon Water, Geelong. The overriding principle is to provide physical redundancy for each main processing function, operated in a modular way with duplication of server hardware. The server cluster consists of two servers for each main purpose: control of reference station connectivity, network processing and user access via a web-browser interface. Remote management, accounting and archiving are also included.

INTERNET CONNECTIONS FOR NTRIP

Users can access the GPSnet servers in real-time or for processing back in the office after the fieldwork is completed. The web interface (see www.GPSnet.com.au) is designed for any type of Internet connection, although latency and reliability, not necessarily bandwidth are the determining factors. Internet enabled phones include General Packet Radio System (GPRS) for Global System for Mobiles (GSM) phones or the equivalent but soon to be defunct Code Divisional Multiple Access (CDMAx1). Third generation wireless (3G) and WiFi *Broadband* services should become more widespread. Internet connections such as ADSL, dialup and VSAT Satellite provide plenty of choice for fixed line or office connections. The current trend for the inclusion of wireless Subscriber Identification Module (SIM) card slots within GPS equipment (especially for surveying applications) provides a complete integrated solution. Generally, mobile Internet is subject to limitations such as coverage area, particularly in rural and remote areas of Victoria. It is intended that the local re-broadcast model presented in Section 2 can overcome user access restrictions from limited mobile coverage.

While the data flow using CORS networks, to a central server cluster and the mobile Internet may appear complex at first, it follows international conventions and can be set-up easily within a GNSS Internet Radio Client or by a GPS distributor. Key to linking CORS networks and users is NTRIP which stands for Networked Transport of RTCM via Internet Protocol. NRTIP was developed to enable the streaming of DGPS or Networked RTK correction data via the Internet. All the user needs is the GNSS Internet Radio Client application for a mobile device, (Phone, Personal Digital Assistant, Pocket PC or Win CE) or PC/Laptop. NTRIP software, GNSS Internet Radio and other tools are available to download for free: (refer to http://igs.ifag.de).

PERFORMANCE MONITORING AND RESEARCH ACTIVITIES

Real-time users understand the importance of signal availability, reliability and integrity. In the case of time-critical applications such as precise machine guidance that operate continuously in demanding environments, reliably of the GPS corrections can be the most important consideration. To reduce the likelihood of catastrophic failures GPSnet architecture includes several quality control processes and redundancies. For example, measures to detect system faults and tools to provide alerts regarding maintenance and other issues. Earlier, SII and University of Melbourne developed the "GQC" quality control program for post-processed data files. Currently, Real-Time Quality Control (RTQC) is a research activity with the CRC-SI. The recent addition of a mobile phone text message service module into the RTQC software will provide system notifications, warnings and operation advice to active users in the field is another example.

NETWORKED REAL-TIME KINEMATIC (NRTK) GPS CORRECTIONS

Results from VICpos and MELBpos have been rigorously tested with industry and academia (Hale *et al.* 2005) with very favourable results. Gordini (2006) found 1-centimetre solutions at 95% confidence when testing MELBpos NRTK and encouraging results at the centimetre level even when the nominal 70 kilometre base-line limits were extended to larger network triangles. For many interested participants, scientific results and terminology can be detailed and quite daunting. What are the actual benefits of Networked Real-time Kinematic (NRTK) over Real-time Kinematic (RTK) and how does NRTK work?

Stand-alone GPS positions without corrections are typically accurate to about 20m with precision close to 5m in ideal environments (*GPS Guide for Users*. DSE 2005). Many circumstances are far from ideal and signal multipath, the reflection of satellite signals bouncing off nearby objects like trees or buildings, is the most common cause of unwanted errors. At worst signal multipath can introduce 100's of metres in error! Purpose built GPS equipment account for multipath in signal processing and antenna design. Differential (DGPS) processing introduces a correction to the satellite code ranges. Based on a known point (reference station) the user's position can be computed to less than 1m with appropriate equipment and practice, due to the reduced effect of atmospheric delays on the satellite ranges (*GPS Handbook*. DSE 2006).

Real-time Kinematic (RTK) goes further by providing satellite carrier phase corrections usually on both L_1 and L_2 GPS frequencies. If the true L_1 carrier phase wavelength ambiguity is determined the position solution can be *fixed* and tracking at a centimetre resolution is possible. Yet RTK suffers from two major limitations: solution extent and correction reception. A fixed centimetre position solution is valid up to distances of about 15 – 20km from the reference station. After this distance the atmospheric effects become more difficult to resolve and a fixed centimetre solution can easily deteriorate to a *float* solution at the decimetre level. Transmission of the RTK corrections from the reference station by UHF/VHF radio frequencies can reach about 20–30km depending on conditions and use of repeater radio systems.

NRTK overcomes the extent and reception issues associated with RTK and provides a number of added benefits. By streaming GPS observation data from individual reference stations to a centralised server, a reference network is created that models GPS ionospheric and tropospheric errors and satellite orbit biases. Technically these biases can be estimated using double difference combinations with code and phase observations on both L_1 and L_2 frequencies or by rigorous physical models for the estimation of all the biases in real-time (Gordini 2006). Regardless of technique the user receives a more reliable correction model based on their location within the network. Virtual Reference Station (VRS) is a network RTK approach developed by Trimble Terrasat (Vollath *et al*. 2001) which generates a "virtual reference station" to imitate a real reference station close to the users' position. In this way increasing the 20km RTK extent to 70km for NRTK.

NRTK corrections are distributed over the Internet (Section 1.33) and when a user has Internet access the RTK radio reception issue shifts from being one of radio range to that of Internet reliability. A combination of *anywhere* Internet coverage and re-distribution with a local radio is presented in Section 2 to address the dilemma of Internet reliability where mobile Internet availability is sparse or problematic.

The NRTK approach also benefits from economies of scale. Total coverage area compounds as additional sites are added to the network. For instance, 6 triangles worked together increase the total coverage area by 118% when compared to the same non-networked individual sites (Denham *et al.* 2006). For example the MELBpos correction service has 7-sites networked together that equates to a coverage area of 14,410 km^2. By adding 2 more proposed sites at Whittlesea (WHIT) and Kyneton (KYNE) the total coverage area will more than double to 29,150 km^2. Further benefits are evident by virtue of continual connectivity and network processing, as each site can be scrutinised for performance and the antenna position monitored for movement.

EXPANSION GPSNET INFRASTRUCTURE IN THE WESTERN DISTRICTS OF VICTORIA

GPSnet consists of 23 collaborative CORS sites (June 2006) that are spaced at approximately 200km intervals across rural and regional Victoria (VICpos) and 70km spacing across Greater Melbourne area (MELBpos). The high accuracy service in the Melbourne and environs relies on the closer spacing to ensure a fixed solution, with centimetre results.

Figure 1 displays the current status and future plans for GPSnet infrastructure. The high accuracy network generating the MELBpos service is expanding to the west by constructing additional reference stations at Ararat (ARAR) and St Arnaud (STAR). Beulah (BEUL) will contribute to the network when data is streamed via VSAT through a VPN tunnel to the processing centre. Extra stations are planned at Cressy or further west towards Hamilton, depending on research outcomes for results using larger network triangles. Additional sites such as Murrayville (MURR) have strong collaborative support for their inclusion with GPSnet.

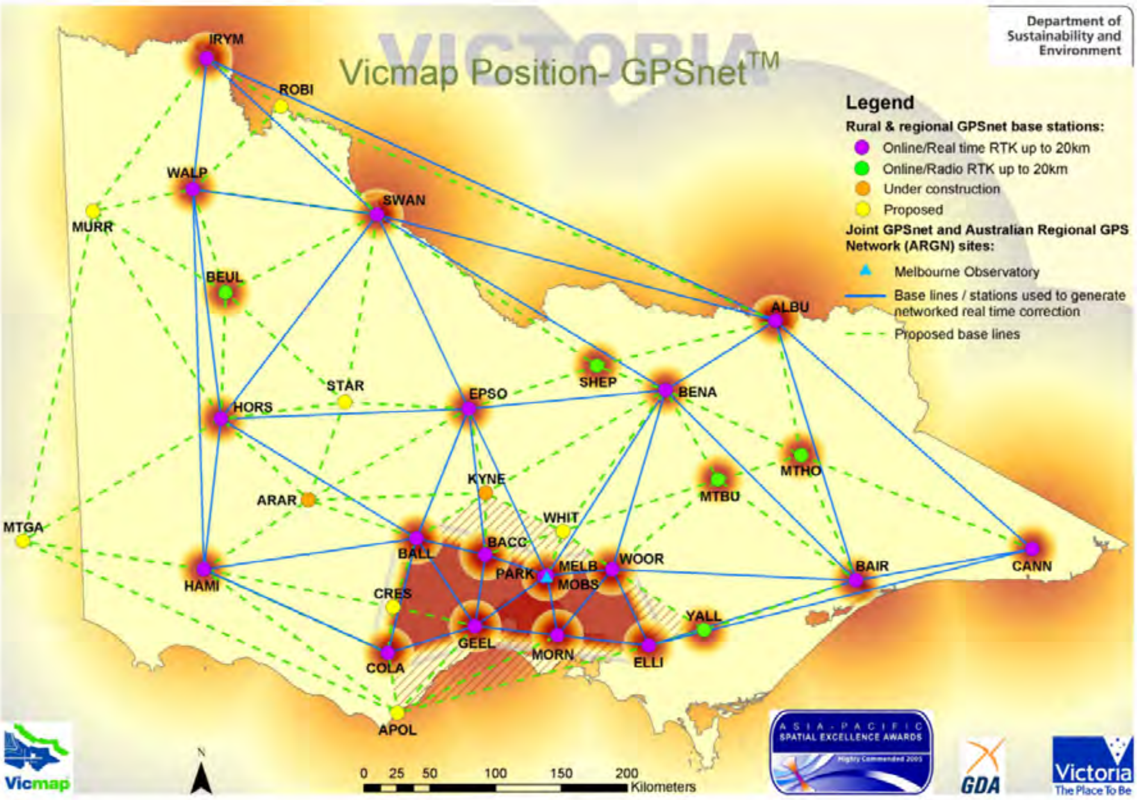


Figure 1. Vicmap Position GPSnet infrastructure

METHODOLGY FOR NRTK DELIVERY: LOCAL RE-BROACAST MODEL

Background

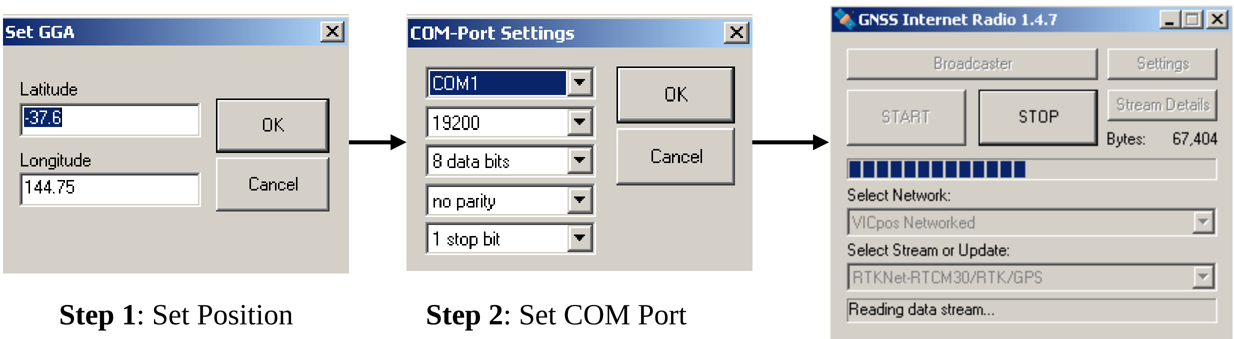
Investigations into a new method for delivery of Internet based NRTK corrections was motivated by the need to supply services for precise machine guidance in rural and regional areas of Victoria. For the most part, high accuracy users in metropolitan areas have access to reliable wireless Internet connections through reasonable GSM/GPRS mobile phone coverage. Distribution of GPS corrections via NTRIP standard over regions where mobile phone coverage is problematic inspired a novel alternative approach. Moreover, advanced GPS equipment designed for surveying includes internal GSM SIM modules, which allows for *plug-and-play* configuration. Less evident is the inclusion by GPS/GNSS manufacturers of GPRS or *Bluetooth* wireless capability with other GPS equipment used in machine guidance. Usually the interfaces available are based on cable (DB9 pin) connections suitable for input from a UHF/VHF radio. Mobile phone with direct cable input is possible assuming coverage is available in the working area. However, such a mobile device with delicate connections may not be durable enough to withstand continual vibrations from heavy machinery operations.

The study was focussed on a two way fixed Internet connection that could be operated anywhere, in combination with a suitable UHF/VHF radio for local transmission of NRTK corrections. VSAT geostationary satellite from NewSat Networks fulfilled the first requirement; while RTK modem/radios from Leica, Micronics, and Trimble were used for on site NRTK re-broadcasts.

GNSS Internet Radio – NRTIP Client application

The GNSS Internet Radio was developed in Europe to stream NTRIP data files over the Internet (Section 1.3.3). In this regard the term “radio” implies the similarity to playing music files (MP3) through the Internet and should not be confused with a local UHF/VHF radio that transmits the corrections to the roving GPS equipment.

The free GNSS Internet Radio application installs readily on a regular PC, with several output options. Figure 2 shows the streamed Bytes for VICpos Networked file based on Latitude –37.5, Longitude 144.75 that is output to a computer COM1 Port. Essentially, the GNSS Internet Radio software transforms the computer into a virtual GPS receiver sending out NRTK corrections from a Com Port, as would a real operational GPS reference receiver!



Step 1: Set Position **Step 2**: Set COM Port **Step 3**: Stream Data

Figure 2. Sequence for GNSS Internet Radio streaming NRTK from a PC COM Port.

SYSTEM DIAGRAMS

The concept to turn a computer with a reliable Internet connection into a virtual GPS reference station receiver by the use of free software and then re-broadcast NRTK corrections over a local radio is illustrated in Figures 3 and 4.

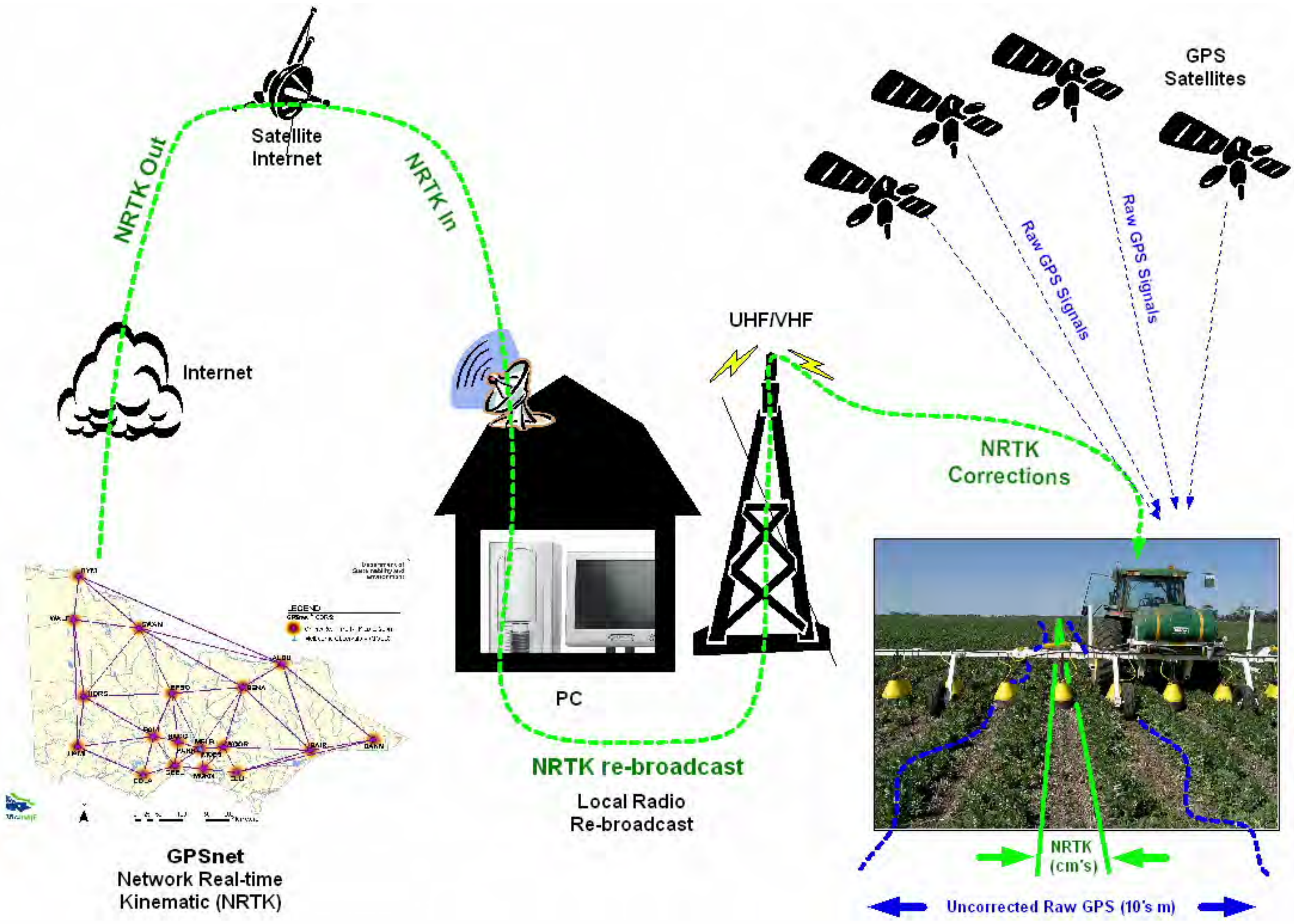


Figure 3. Schematic illustration of system data flow for the re-broadcast model

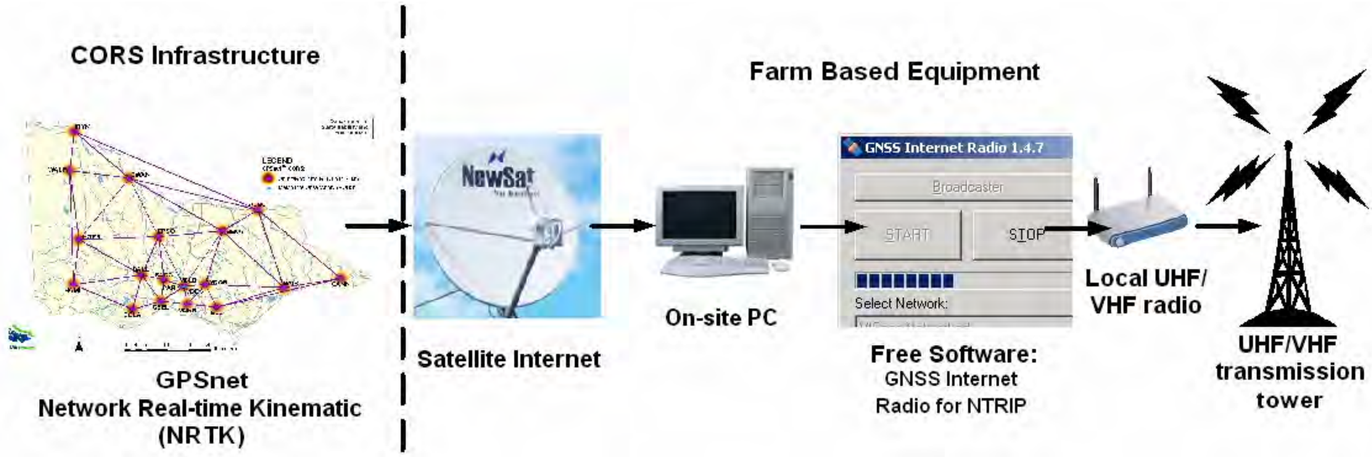


Figure 4. Modular system components of the re-broadcast model

The modular components that transform a PC into a virtual GPS reference receiver include the following: GPSnet infrastructure properly configured to generate NRTK corrections at the user location. A reliable Internet connection at the location, VSAT is good a choice for remote areas. PC to load up free software that connects to GPSnet services to stream correction data out the PC COM Port. Local UHF/VHF radio that connects into the back of the PC COM Port and re-broadcasts the NRTK corrections out to be received by a GPS application in the field.

RESEARCH AND RESULTS

Proof-of-concept tests have now been performed to verify that a radio re-broadcast solution is feasible for delivery of NRTK corrections. The major system level components used for a radio re-broadcasting NRTK solution include the following:

- VICpos and MELBpos correction services
- Internet Service Provider (ISP)
- Personal computer acting as Virtual Reference Station and running GNSS Internet Radio for delivery NRTK corrections via NTRIP
- Pair of UHF/VHF data radio modems
- Dual frequency GPS receiver

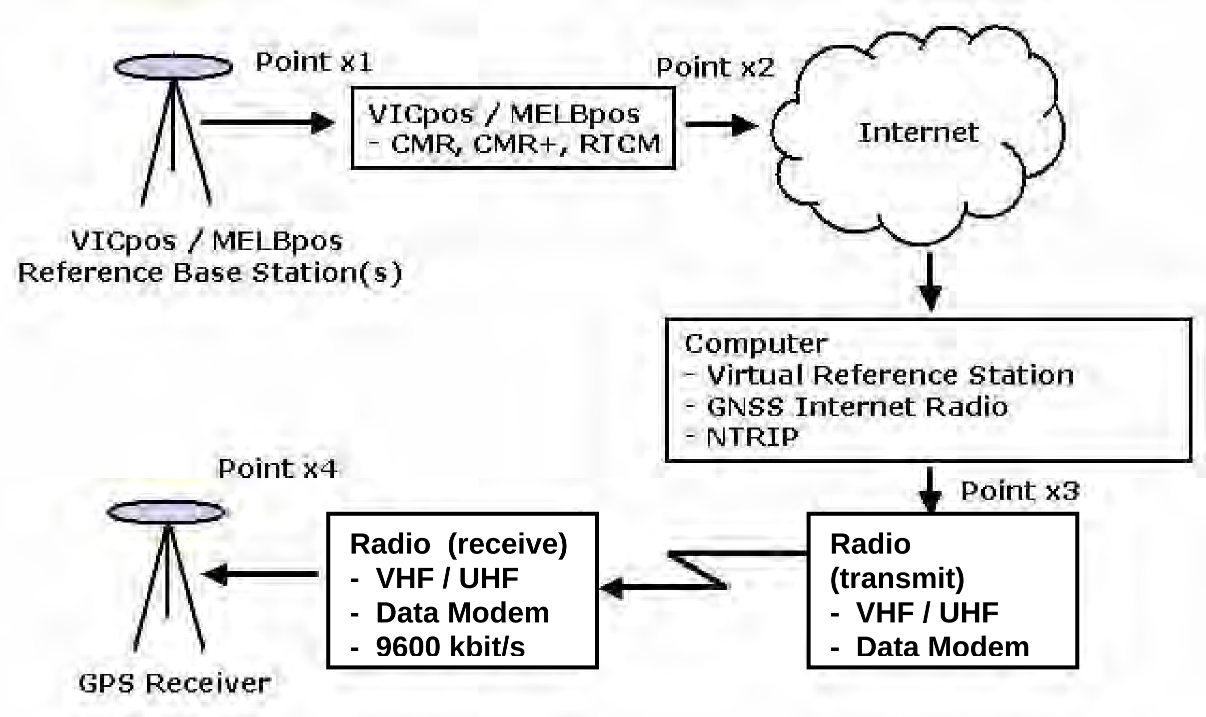


Figure 5. Generic test system

Tests were conducted using VICpos for both single base (RTK) and network based (NRTK) solutions. The transmission interval of correctional data packets sent from the central server cluster was configurable and varied between 1 second and 5 seconds. The size of the correctional data packet is dependent on the format desired by the GPS receiver (CMR, CMR+, RTCM2.3, 3.0). Typically the packet is only a few hundred bytes long.

A number of ISPs were used in the trial including a narrowband dialup connection, an ADSL broadband connection, and a 256/256kbps satellite link provided by NewSat. The size of a correctional data packet delivered by VICpos is relatively small; subsequently it is not the physical bandwidth that affects delivery of an NTRIP packet to a VRS, but the traffic congestion and quality of service. These two characteristics are variable, non-deterministic and can affect the latency and interval rate of data packets arriving at the VRS. Consequently statistical data was captured on packet latencies and interval rates observed between the VRS and VICpos server (labelled Point x2 and Point x3 in Diagram 5). It is intended to use this data to form a correlation between packet latency, interval rates and positional accuracy during the next test phase.

The VRS used GNSS Internet Radio (NTRIP) application software to stream the correctional data, over the Internet to a data radio modem. The connection between the PC and the radio was via a standard DB9 serial cable configured at 9600 kbit/s. Two types of data radio modems were used in this trial; a pair of Micronics VHF radios configured to operate at 9600 kbit/s half duplex and a pair of Trimble SNB900 radios. For the purpose of this test it was assumed that the radio link added no adverse effects to the delivery of correctional data packets to the GPS receiver. Three different GPS receivers were tested including a Trimble R8, Trimble 5700, and a Leica GPS1200. All three receivers proved capable of obtaining NRTK initialisation and providing a fixed position solution to sub-decimetre accuracy.

PACKET DELIVERY MEASUREMENTS

Traffic congestion, network throughput and quality of service are the key criteria of the Internet that impact on the ability to deliver NRTK correctional data to a GPS receiver. Latency is an important factor in broadcasting GPS corrections. Latency that exceeds more than 1-second can affect the accuracy on the ground particularly for dynamic applications such as precise machine guidance. Two metrics were captured to characterise the delivery of correctional data packets over Internet: the packet latency and the packet interval.

Round Trip Time (RTT) of data packets were measured as an indicator of latency and the timestamp of two consecutive packets were recorded to calculate the variation of the packet interval. Both these characteristics influence the accuracy of a NRTK measurement when using radio re-broadcasting via the Internet. Ideally when using NRTK in conjunction with Internet radio re-broadcasting, a user should strive to minimise packet latency and have a steady and consistent packet interval rate. The following packet delivery measurements summarise the observations made with three different Internet Service Providers. The VICpos server was configured to send correctional data packets at an interval of 1 per second and a 500-packet sample was observed at the VRS.

Measurement / ISP	**Dial Up Narrowband**	**ADSL Broadband**	**Satellite Broadband**
Packet Latency – Minimum	130 ms	40 ms	640 ms
Packet Latency – Maximum	181 ms	110 ms	1562 ms
Packet Latency – Average	136 ms	41 ms	800 ms
Packet Interval – Minimum	0.270 s	0.220 s	0.746 s
Packet Interval - Maximum	3.424 s	2.300 s	1.237 s
Packet Interval - Average	1.001 s	1.005 s	0.998 s

Table 1. Packet Latency and Packet Interval Comparisons

DISCUSSION

The progression from a concept to the completion of the initial testing phase has been a significant step to demonstrate the viability of a local re-broadcast delivery model for NRTK corrections. Already, testing has identified that it is not necessarily physical bandwidth that influences delivery of an NTRIP packet to a VRS, but the Internet traffic congestion and quality of service. To this end a more complete understanding of the time delays in the system as a whole is very important.

Measurement and determination of time delays will form part of the next round of tests in order to from a correlation between packet latency, interval rates and positional accuracy. Latency tests will take part on known ground marks located at Beremboke near Geelong, Victoria.

Use of a mobile VSAT service from NewSat, with latency techniques being developed as part of the research component, will assist to identify the Committed Information Rate (CIR) required for the most efficient NRTK transmission and reception. Contemporaneous configuration of the VICpos server processing interval at 1, 2, 3 or 5 seconds will also be monitored to optimise the NRTK output stream. When using NRTK in conjunction with Internet radio re-broadcasting, the application must receive packets with minimal latency with a reliable and consistent packet interval rate.

Importantly, availability of mobile VSAT services will facilitate links with other research activities. Such as testing the latency of GSM/GPRS corrections at Beremboke and research associated with long base-line NRTK for network triangles larger than the normally accepted VRS base-line length of 70 km's.

The NRTK re-broadcast model now provides a favourable backdrop for increased end-user involvement. Further testing on dynamic machine guidance applications will expand appreciation of pass-to-pass relative precision and assessment of year-to-year accuracy under varying operational conditions.

CONCLUSION

This paper has briefly described CORS architecture developed to generate Networked Real-time Kinematic (NRTK) corrections from Victoria's GPSnet infrastructure. A brief background on NRTK and explanations of the benefits of networked RTK approach over single reference station RTK followed. Advanced survey equipment integrated with GSM/GPRS wireless Internet capabilities have been successfully trialed using MELBpos NRTK with real-time results reported by enthusiastic participants at 1-centimetre accuracy. Fortunately, most metropolitan users have a choice of equipment and telecommunications infrastructure to set up high accuracy applications. In the regional areas, users are challenged by more difficult circumstances including sparse telecommunications coverage and legacy equipment, designed with ports for serial cable not internal wireless Internet capability. The need to provide high accuracy positioning services in rural parts of Victoria motivated the investigation into a practical NRTK delivery system. The concept of transforming a PC loaded with free software and a reliable Internet connection into a virtual reference station GPS receiver was proposed for the task.

The model based on a combination of ubiquitous Internet connection like VSAT and a local radio re-broadcast was validated. Initial tests identified correction packet latency and packet consistency as significant factors that will impact on performance. In the near future the research component will attempt to correlate packet metrics with positional accuracy. Meanwhile the active participants provided support and encouragement for adoption of the re-broadcast model. The system has proved to be a viable and effective alternative to mobile wireless connectivity, currently the most popular means of access to NRTK correction data from GPSnet infrastructure.

AKNOWLEDGEMENTS

The authors wish to acknowledge all those who have participated in the supply of equipment and services to assist with testing and research activities. In particular Andrew Whitlock from Department or Primary Industries (DPI) Victoria, Stuart Dasler (NewSat Networks) John Koles (MICRONICS GPS), Bernie Edmonds (CR Kennedy) and Paul Standen, Paul Andrews (Ultimate Positioning).

REFERENCES

Cooperative Research Centre for Spatial Information (CRC SI) [Internet]. Available from: <http:/ http://spatialinfocrc.org/> Accessed 18 June 2006.

Denham, J. Whitlock, A. and Yule, D. (2006) Contemporary Position and Navigation Needs of Precision Agriculture and Victoria's GPSnet™ CORS Network, International Global Navigation Satellite Systems Society IGNSS Symposium 2006, Proceedings, Queensland.

DSE (2003) *Global Positioning System Handbook* – Standards, Specifications and Best Practice 2003, Updated 2006 [Internet]. Available from: <http://www.land.vic.gov.au> Accessed 18 June 2006.

DSE (2004) *GPS A Guide for Users* ISBN 1 74152 013 4 [Internet]. Available from: <http://www.land.vic.gov.au> Accessed 18 June 2006.

DSE (2006) GPSnet: GPSnet Base Station Host Agreement Internet]. Available from: <http://www.land.vic.gov.au> Accessed 18 June 2006.

DSE (2006) Spatial: Vicmap Position – GPSnet Product Description [Internet]. Available from: <http://www.land.vic.gov.au> Accessed 18 June 2006.

Gerhard, W. (2006) Towards NTRIP 2.0 and Potential Future Properties, Proceedings of NTRIP Symposium and Workshop: Streaming GNSS Data via Internet, Frankfurt, Germany, February 6-7, 2006.

Gordini, C. (2006) Testing and Evaluation of a GPS CORS Network for Real Time Centimetric Positioning – The Victoria GPSnet™ International Global Navigation Satellite Systems Society IGNSS Symposium 2006, Proceedings, Queensland.

Hale, M. Millner, J. Ramm, P. Wilson, W. Kealy, A. (2005) VICpos Performance Assessment, Proceedings of SSC 2005 Spatial Intelligence, Innovation and Praxis: The national biennial Conference of the Spatial Sciences Institute, September, 2005. Melbourne: Spatial Sciences Institute. ISBN 0-0-9581366-2-9

Hale, M. Collier, P. Kealy, A. Ramm, P. Millner, J. (2006) Validating a Model for CORS Network Management, International Global Navigation Satellite Systems Society IGNSS Symposium 2006, Proceedings, Queensland.

Millner, J. Hale, M. Standen, P. Talbot, N. (2004) The development and enhancement of GNSS/GPS Infrastructure to Support Location Based Service Positioning Systems in Victoria, International Symposium on GNSS/GPS, 2004, Sydney.

NTRIP http://igs.ifag.de

Ramm, P. Hale, M. (2004) Realisation of the Geodetic Datum in Victoria, GNSS 2004, Proceedings of the 2004 International Symposium on GNSS/GPS, Sydney, Australia.

Vollath, U. Landau, H. and Chen, X. (2002) Network RTK versus Single Base RTK –Understanding the Error Characteristics, Proceedings of the 15th International Technical Meeting of the Satellite Division of the Institute of Navigation, Portland, Oregon, USA, September.