University of Southern Queensland

Faculty of Engineering and Surveying

Development and Testing of

a Portable GNSS Network Solution

using the Magellan ProMark3.

A dissertation submitted by

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in

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ABSTRACT

With increasing development and expansion of Continuously Operating Reference Station (CORS) networks, globally and at home such as Sydnet, Global Navigation Satellite System users have greater options of utilizing reference station networks to receive correction data and undertake Real Time surveys without the need of supplying their own base station. A large majority of GNSS built today are equipped with built in mobile technology which utilize bidirectional communication including Internet based cellular connections. With increasing coverage of wireless internet, users will be able to utilize this technology in more places than they could ever before.

The ProMark3 RTK GNSS receiver transmits correction data via a conventional 0.5 watt UHF radio. This allows a working range of up to 1.5km in open areas and 0.3 – 0.7km in urban built up areas. Unidirectional communication such as UHF also has its limitations including line of sight requirements, transmitter power, broadcasting antenna height limitations, reliability of the link and governmental restrictions such as licensing and operational limitations. Alternative options for receiving correction data are made available within the ProMark3's onboard software, which include Networked Transmit of RTCM via Internet Protocol (NTRIP) and Direct Internet Protocol (DIP). These methods can extend that working range to 10km which is the recommended limit for RTK surveying. Built in wireless technology is not present in the ProMark3 however the user can still connect using a separate web enabled phone with Bluetooth technology. The advantage with this option is that the phone can be still used whilst you work, giving you even greater flexibility.

This research project will explore the performance of the ProMark3 using Direct IP. Two different portable base reference stations to broadcast corrections will be designed. They include an office based and field based system. A rigorous testing regime will be conducted to explore the achievable range using Direct IP, the repeatability of position on an established baseline and the time taken to achieve a fixed solution at certain distances. The final part of this project will discuss the application of the technology to the surveying industry, particularly issues of reliability, cost and quality control.

The use of CORS as an alternative to receiving correction data is improving work turn around time and field efficiencies, improving security as only one GPS is being utilized and offering survey firms the chance to experiment with this technology without a large expense upfront.

The concept of a portable Direct IP station will allow users to operate privately run reference station networks from the office or the field. The benefit of a portable base station is that you can disassemble the base quickly and take it anywhere you decide to work. This will allow the operator and other users the chance to access data in areas not serviced by CORS and create opportunities for surveyors wanting to experiment with this alternate technology. The future may see an increasing amount of private CORS setup operating within existing government run networks, offering users even greater choice to access spatial data.

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CERTIFICATION

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in this dissertation are entirely my own efforts, 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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(Signature)

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(Date)

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At the beginning of this project I had never used GPS in my working life as a surveyor. The idea of taking on this project was exciting and challenging. I knew very little about CORS, VRS and Direct IP. With the numerous problems and situations I had to overcome I am very confident with my new ability and have achieved a life long dream of finally understanding the mystery behind GPS.

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NOMENCLATURE AND ACRONYMS

The following abbreviations have been used throughout the text and bibliography:-

AR   Ambiguity Resolution

DGPS   Differential Global Positioning System

DIP   Direct Internet Protocol

GNSS   Global Navigation Satellite System

GPRS   General Packet Radio Service

GSM   Global System for Mobile Communication

IP   Internet Protocol

ISP   Internet Service Provider

NTRIP   Networked Transport of RTCM via Internet Protocol

PM3   ProMark3

SBAS   Satellite Based Augmentation System

TCP/IP   Transmission Control Protocol/Internet Protocol

TTF   Time to Fix (Time taken to achieve a Fixed Solution)

CHAPTER 1 - INTRODUCTION

1.1   Research Statement

The Magellan ProMark3 is a single frequency RTK GNSS receiver with a working range of up to 1.6km line of site, using unidirectional communication methods such as 0.5 watt UHF spread spectrum radios. This range may be slightly improved using 2 watt 3rd party radios. With the use of mobile phone technology, the ProMark3 can connect to Continuously Operating Reference Station (CORS) extending that range to 10km which is recommended limit for single frequency RTK.

The ProMark3 uses GPS and Satellite Based Augmentation System (SBAS) to achieve faster initialization times. Some CORS do not support the use of SBAS and therefore times to achieve a fixed solution will take longer. There are currently large swaths of land in Australia and around the world not supported by CORS.

This research project will find a solution to the working range problem of the ProMark3. By developing a portable GNSS solution, GPS and SBAS differential corrections will be transmitted using Direct IP over the internet. This will extend the working range of the ProMark3 and allow for faster initialization times. The benefit of a portable solution will allow the user to put the system to use into those areas not supported by CORS and still maintain the advantages offered by this advancing technology.

1.2 Research Aims and Objectives

1.21 Aim

The aim of this research is to improve the range capability of the Magellan ProMark3 RTK by developing a portable GNSS network solution using Direct IP.

1.22 Objectives

1. Conduct a review of literature into the use of Virtual Reference Systems and CORS network initiatives with particular reference to the use of internet protocols.

2. Establish a portable home/ office and field network GNSS data stream via the Internet, using a Magellan ProMark3 base.

3. Establish a robust testing regime for accuracy, reliability, range, repeatability, efficiency, capacity, cost and latency of the ProMark3 receiver using Direct IP including its application to conventional survey operations.

4. Evaluate different freeware and shareware programs in terms of their operation and capabilities.

5. Undertake field testing and analysis of data in various configurations.

6. Analyze and discuss the results of the field experiments and discuss the application of the technology to the survey industry, particularly issues of reliability, cost and quality control.

1.3   Background to Problem

The ProMark3 (PM3) comes standard with a licence free 0.5 watt spread spectrum radio as shown in Figure 1.1, providing up to 1.6km line of sight communication. In built up urban areas it is limited to between 300 and 700 metres. With third party 2W radios that range can be increased to 2km in built up urban areas.

Figure 1.1 - ProMark3 with licence free 0.5 watt radio (Source: ProMark3 RTK White Paper 2007)

With the use of Continuously Operating Reference Stations (CORS) you can increase the operating range to about 10km. This is the recommended limit for single frequency RTK as beyond that distance dependent biases such as orbit error, ionospheric and tropospheric signal refraction can occur.

The ProMark3 uses SBAS for faster initialization. Local CORS such as Sydnet do not transmit SBAS data. In early testing of the ProMark3 using NTRIP with Sydnet, I was able to obtain a horizontal accuracy of 2cm at a range of 16km. However, it took nearly 30 minutes for the rover to initialize.

1.4   Conclusion

The focus of this research project is to test and improve the range performance of the ProMark3, by using Direct Internet Protocol (DIP) to transmit GPS and SBAS data. A rigorous testing regime will be conducted investigating latency, repeatability, efficiency and accuracy of the system. The use of Direct IP software applications to transmit the data will also be explored.

Direct IP will be more prevalent with single frequency RTK because of the shorter range, but over Australia there are whole swathes of land that would currently be more than 50km from a CORS network. With the investigation of a portable GNSS solution using Direct IP and with the affordability of the ProMark3, longer range RTK would be possible and very useful.

Having defined an approach for researching the problem to meet the stated aim and objectives, the next chapter, the Literature Review, connects the project problem to the external environment and places.

CHAPTER 2 – LITERATURE REVIEW

2.1   Introduction

The purpose of this section is to conduct a review of literature into the use of internet protocols with Continually Operating Reference Stations (CORS) and Virtual Reference Stations (VRS).

The aim of the literature review is to explore the limitations of RTK GPS and provide a thorough understanding of the concepts behind CORS and VRS.

Research has been undertaken to investigate IP streaming for Real Time GNSS applications. Such IP streaming applications include Networked Transport of RTCM via Internet Protocol (NTRIP) and Direct Internet Protocol (DIP) which forms the major focus of this research project. Further explanation is made about these two applications and then finally reviewing previous research and testing of those server applications by others.

2.2   Real-Time Kinematics (RTK) Surveying and limitations

Investigations began in the mid 1990's to find the optimal way of processing reference receiver data, and then providing "correction" information to users, in real time. This practice is known as RTK Surveying (Rizos and Han 2003).

RTK positioning with GPS as shown in Figure 2.1, is a common survey technique used today. RTK GPS allows the use of a static 'reference station' with known coordinates, while the second 'user' receiver simultaneously tracks the same satellite signals. When the carrier phase measurements from the two receivers are combined and processed, the mobile user's receiver coordinates are determined relative to the reference receiver. This can be done in real-time, if the reference receiver data is transmitted to the user's receiver, even while the receiver is moving.

Figure 2.1 - ProMark3 RTK System

(Source: Gemini Positioning Systems Limited viewed February 08,

http://gps1.com/magellan_promark3rtk.html)

With modern equipment only a few tens of seconds of data are typically required to fix the ambiguities associated with the GPS phase data observable and compute a baseline; the difference in latitude, longitude and height between the reference and rover positions (Higgins 2002). The ultimate implementation of such a technique is known as 'real-time kinematic' (RTK), and is capable of cm-level accuracy under certain constrained operational conditions (Rizos, 2002).

One critical limitation of this conventional RTK approach is that the distance between the reference and rover receivers must be less than about 20km in order to be able to resolve the integer ambiguities reliably 'on-the-fly' (i.e. in kinematic mode). This limitation is due to distant dependent biases such as the GPS satellite orbit error, and the ionospheric and tropospheric signal refraction (Zhang et al 2007a).

Wubbena et al (1996) maintains that RTK can provide centimetre position accuracy, though the accuracy and reliability of the standard RTK solution decreases with increasing distance from the reference station.

Classical RTK GPS requires that distances between the roving GPS unit and reference station should not exceed 10km to achieve a horizontal accuracy better than 10mm +/- 1ppm (HNTB 2004). This limitation on distance between the base station and mobile rover is due to systematic effects of ephemeris, troposphere and ionospheric errors. These errors result in an increased initialisation time and reduced accuracy (Wubbena et al. 1996). For most surveying work the 10km range would be sufficient but when completing a survey that covers a large area and requires measurement of longer baselines, then these distance dependent errors become significant.

The limitations of RTK surveying have been highlighted and have led to the development of a system of networked reference stations.

2.3   Real Time Networks

2.31   Continuously Operating Reference Stations (CORS)

CORS are defined as GNSS receivers located permanently at sites having very accurately pre-determined coordinates. A CORS tracks GNSS satellites continuously 24 hours a day and may be an individual receiver (single base) or may form part of a group of receivers strategically located across a region. Groups of CORS are referred to as CORS networks. Such networks may span areas of several tens of kilometres in dimension (i.e. Sydnet) as shown in Figure 2.2. CORS networks can cover larger regional areas, continental or even on global scale.

Figure 2.2 - Sydnet coverage area (Source: Sydnet viewed Feb 08, <http://sydnet.lands.nsw.gov.au>)

High quality GPS reference stations have been established, in a sparse global network, since the late 1980's to support scientific applications such as tectonic/seismic research, geodetic reference frame definition and maintenance, and for atmospheric studies (Zhang et al 2006).

These stations are located hundreds, or even thousands of kilometres apart. However, by improving the availability of reference station data for users that demand high positioning accuracy, reliability and integrity in real-time, the variety of applications can grow rapidly. CORS networks are therefore critical ground-based infrastructure enabling the basic utility of high accuracy positioning to become available to a diverse range of users (i.e. surveying, precision farming, structural monitoring, etc).

Zhang et al (2006), states that regional CORS networks are currently being established in many countries as part of the foundation for the spatial data infrastructure. The future may see CORS systems replacing permanent survey marks or geodetic trig stations which are used for precise surveys.

The distribution and density of a CORS network is constrained by the establishment costs per reference station, the area to be serviced and positioning accuracy requirements (Zhang et al 2006).

Existing CORS networks in countries such as Germany, UK, Denmark, Austria and Japan are sufficiently dense to restrict the maximum baseline length between a user and a nearby reference station to be well under 40km (Zhang et al 2006), which is generally sufficient for cm-level accuracy techniques based on a single reference station, using high quality, dual frequency receivers that permit rapid "ambiguity resolution" (AR). However, as the inter - receiver distance increases, the residual atmospheric biases (due to differential ionospheric and tropospheric delay of the GPS satellite signals) in the double differenced GPS observable increases, make AR more difficult (and even impossible using current rapid positioning techniques). Hence this distance constraint for rapid AR makes accurate positioning with respect to sparse CORS networks problematic, and this has profound ramifications in Australia due to its large area and relatively sparse population (Zhang et al 2006).

2.32   Network RTK

The use of a network of reference stations instead of a single reference station allows you to model the systematic errors in the region and thus provides the possibility of an error reduction.

This allows a user not only to increase the distance at which the rover receiver is located from the reference, it also increases the reliability of the system and reduces the RTK initialization time. The concept can be used not only to set-up new networks, but also to improve the performance of old, established networks. The network error correction terms can be transmitted to the rover in two principle modes namely;

1. A Virtual Reference station mode. This mode requires bi-directional communication. The basic advantage of this mode is that it makes use of existing RTCM and CMR standards implemented in all major geodetic rover receivers and thus is compatible with existing hardware.

2. A broadcast mode, in which the error corrections due to atmospheric and orbit effects are transmitted in a special format, which requires changes of rover receiver hardware or additional hardware to convert the non-standard format to a standard RTCM data stream before used by the rover.

2.33   Virtual Reference Station (VRS)

A virtual reference station is a simulation of a reference station. At any position in the network's coverage area, the control centre can approximate the correction data that a reference station would send if it were located at that position. The control centre uses information from all other stations to compute these corrections. VRS requires bi-directional communication between rover and the control centre. (Peterzon 2004).

As you can see in Figure 2.3, the GPS rover sends its approximate position to the control center. It does this by using a mobile phone data link, such as GSM or GPRS, to send a standard NMEA position string called GGA. The control center will accept the position, and responds by sending RTCM correction data to the rover. As soon as it is received, the rover will compute a high quality DGPS solution, and update its position. The rover then sends its new position to the control centre.
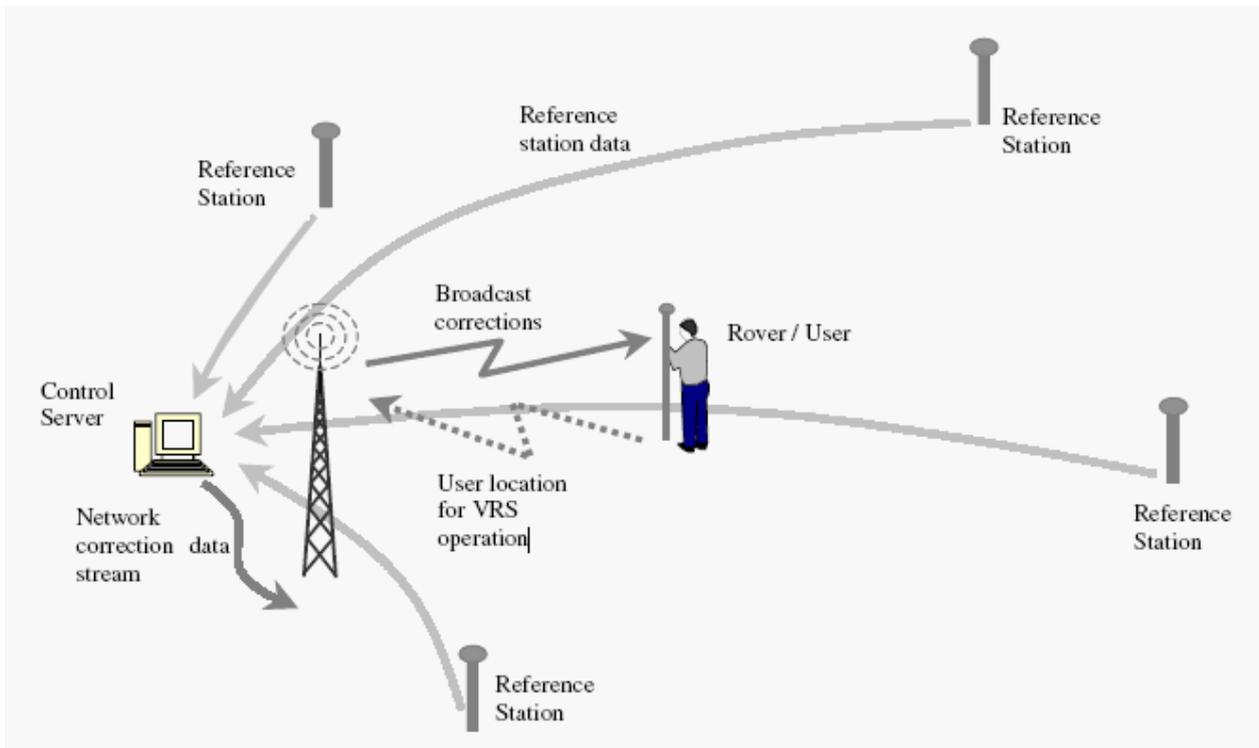
Figure 2.3 - Network RTK system and data flow (Source: Talbot et al 2002)

The network server will now calculate new RTCM corrections so that they appear to be coming from a station right beside the rover. It sends them back out on the mobile phone data link (i.e. GSM or GPRS). The DGPS solution is accurate to +/-1 meter, which is good enough to ensure that the atmospheric and ephemeris distortions, modeled for the entire reference station network, are applied correctly.

This technique of creating raw reference station data for a new, invisible, unoccupied station is what gives the concept its name, "The Virtual Reference Station Concept". Using the technique, it is possible to perform highly improved RTK positioning within the entire station network.

2.4   Internet Streaming of RTCM via Internet Protocol.

2.41   Internet Protocols

The Internet Protocol (IP) is the method or protocol by which data is sent from one computer to another on the Internet. Each computer (known as a host) on the Internet has at least one IP address that uniquely identifies it from all other computers on the Internet. When you send or receive data (for example, an e-mail note or a Web page), the message gets divided into little chunks called packets. Each of these packets contains both the sender's Internet address and the receiver's address. Any packet is sent first to a gateway computer that understands a small part of the Internet. The gateway computer reads the destination address and forwards the packet to an adjacent gateway that in turn reads the destination address and so forth across the Internet until one gateway recognizes the packet as belonging to a computer within its immediate neighborhood or domain. That gateway then forwards the packet directly to the computer whose address is specified.

Because a message is divided into a number of packets, each packet can, if necessary, be sent by a different route across the Internet. Packets can arrive in a different order than the order they were sent in. The Internet Protocol just delivers them. It's up to another protocol, the Transmission Control Protocol (TCP) to put them back in the right order.

TCP/IP (Transmission Control Protocol/Internet Protocol) is the basic communication language or protocol of the Internet. It can also be used as a communications protocol in a private network (either an intranet or an extranet). When you are set up with direct access to the Internet, your computer is provided with a copy of the TCP/IP program just as every other computer that you may send messages to or get information from also has a copy of TCP/IP.

TCP/IP is a two-layer program. The higher layer, *Transmission Control Protocol*, manages the assembling of a message or file into smaller packets that are transmitted over the Internet and received by a TCP layer that reassembles the packets into the original message. The lower layer, *Internet Protocol*, handles the address part of each packet so that it gets to the right destination. Each gateway computer on the network checks this address to see where to forward the message. Even though some packets from the same message are routed differently than others, they'll be reassembled at the destination.

TCP/IP uses the client/server model of communication in which a computer user (a client) requests and is provided a service (such as sending a Web page) by another computer (a server) in the network. TCP/IP communication is primarily point-to-point, meaning each communication is from one point (or host computer) in the network to another point or host computer. TCP/IP and the higher-level applications that use it are collectively are said to be "stateless" because each client request is considered a new request unrelated to any previous one (unlike ordinary phone conversations that require a dedicated connection for the call duration). Being stateless frees network paths so that everyone can use them continuously. (Note that the TCP layer itself is not stateless as far as any one message is concerned. Its connection remains in place until all packets in a message have been received.)

Many Internet users are familiar with the even higher layer application protocols that use TCP/IP to get to the Internet. These include the World Wide Web's Hypertext Transfer Protocol (HTTP), the File Transfer Protocol (FTP), Telnet (Telnet) which lets you logon to remote computers, and the Simple Mail Transfer Protocol (SMTP). These and other protocols are often packaged together with TCP/IP as a "suite."

2.42 Internet Streaming of RTCM

The Internet and associated applications and have seen explosive growth in recent years. Techniques for the provision of multimedia content via the internet have become common place, examples being web-tv, MP-3 files, internet radio and web based telephone services. In addition to the availability of streamed content on the internet, mobile communication network providers have enabled the widespread availability of wireless internet access (Elmar LENZ, 2004).

With the growing possibilities of the Internet and the increase in the available bandwidth, applications like Internet-Radio or Internet-TV data streaming are becoming mature and stable.
The use of the Internet as a medium for transmitting GNSS code and phase corrections for real-time surveys has led to much research into this new idea.

Corrections broadcast via Internet are in fact available from an assigned Web address and port, therefore several users can connect with any wireless system (GSM, GPRS, UMTS) and through any Internet provider to that address and download in real time the differential corrections. This has an

advantage over radio transmissions. The user by is not bound to a limited range from the reference station, as long as the client has a connection to the Internet.

On the other hand, this method has some drawbacks such as high network latency times and sudden disconnections from the server during the survey. Latency is surely one of the greatest problems, especially in RTK surveys, and is substantially tied to the data transmission rate, and thus the system used for connecting to the Internet (Pala et al, 2004)

The advent of wireless broadband service with its substantially higher data rate could enable new techniques not possible previously to be used by GPS users (Yan.2004). Unlike voice networks, this technology is pure IP and is dedicated to data service. Wireless broadband has superior data rate compared to the three technologies mentioned previously. Its maximum speed is at around 1 Mbps which is almost three times that of 3G technology.

The main disadvantage of wireless broadband networks is that they are relatively new and their network coverage is nowhere that of voice networks such as GSM and CDMA. The iBurst network for example, is only available in metropolitan area of New South Wales, Queensland and Victoria. Another network, *Unwired*, so far is only available in Sydney and now Melbourne. However, it is expected that as this technology gains popularity, their network coverage will expand and cover more areas. Part of this research project will investigate the use of wireless broadband to receive and to distribute RTCM data.

The transmission of differential corrections can be performed by 3 server applications. Direct IP server (Direct Internet Protocol) and NTRIP server (Networked Transport of RTCM via Internet Protocol) and Mirror Mode which allows the base station to broadcast its corrections over the internet and the server can be in another country and still host multiple users.

2.5   Differential Correction Servers

2.51   Direct IP

Direct IP is the main focus of this research and involves a single base reference station broadcasting corrections as shown in Figure 2.4. The station consists of a GPS receiver connected to a computer server via a null modem serial cable. The user connects to the server according to the IP address and TCP port number. This method can be used for CORS, VRS, FKP and SPIDER networks. You do not need a username or password. The provider of the corrections has no control or way of monitoring your usage. Hence Direct IP is usually provided for internal organizations.
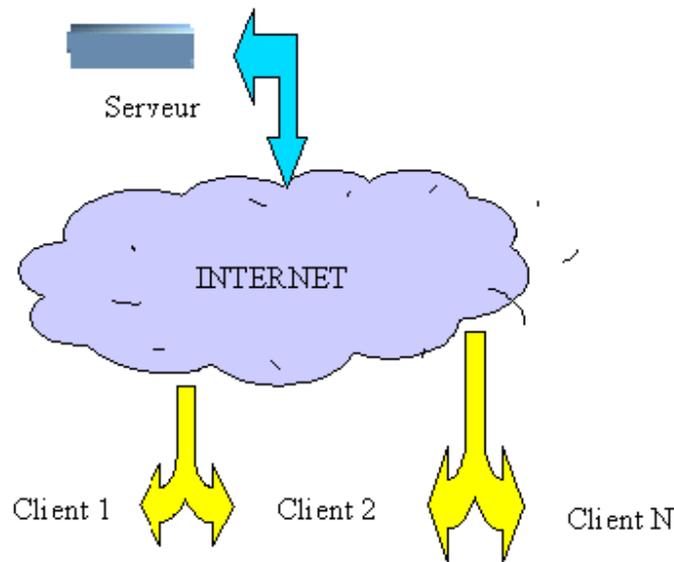
Figure 2.4 - Direct IP Concept (Source: Utilserver Reference Manual, v1.7.0)

2.52   NTRIP

A new technique using the Internet for streaming and sharing Differential GPS corrections (DGPS) to allow precise positioning and navigation was announced in 2004 named "Networked Transport of RTCM via Internet Protocol (NTRIP)". The development of this new technique was carried out by the

Federal Agency for Cartography and Geodesy (BKG) Germany, together with partners including the University of Dortmund and Trimble Terrasat GmbH. The main intention is using the "Internet" more or less as an alternative from the current existing real-time correction services provided via radio transmission (LF, MF, HF, UHF) or mobile communication networks like GSM, GPRS, EDGE or UMTS. NTRIP is a generic, stateless protocol based on the Hypertext Transfer Protocol HTTP/1.1 and is enhanced to GNSS data streams.

NTRIP is used to connect a CORS, VRS, FKP or SPIDER system also. The provider of the corrections supplies you with a username, password, IP address and port number. The provider controls your access and knows when, where and for how long you are connected. This information can be used to monitor and charge for your usage. NTRIP has an extra layer of Protocol and is said to be slightly slower than Direct IP.
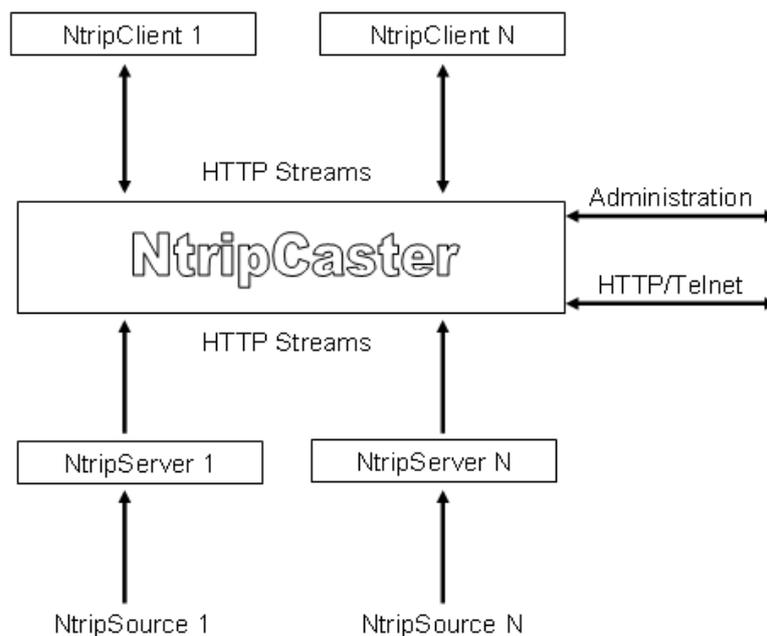
Figure 2.5 – NTRIP System Concept (Source: Weber et al, 2005)

The basic system elements of NTRIP are the NTRIP Source, The NTRIP Server and the NTRIP Caster which are explained in more detail below.

NTRIP Source:

The NTRIP Source is a GNSS receiver that provides continuous GNSS data such as RTCM-104 corrections that refer to a known or specific location. A USA organisation, the Radio Technical Commission for Maritime Services (RTCM), works within a special Committee No. 104 (SC- 104) with 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. The HTTP-based TCP protocol NTRIP is currently undergoing this process via the special committee No. 104 to become a worldwide standard.

NTRIP Server:

In practice, the NTRIP Server is software running on a conventional PC that sends correction data from a GNSS receiver (COM-port) to a third installation (from NTRIP Source to NTRIP Caster). NTRIP can be used within a virtual reference network where the protocol is able to transport RTCM data. The RTCM corrections could be taken into consideration at the users approximate position. This virtual reference station data is comparable with a NtripSource that could be transmitted by one of the Ntrip components, the NtripServer. The NtripServer transports GNSS data of an NtripSource (GNSS receiver) directly to the NtripCaster. Before doing this in the described way the NtripServer sends a request to the mountpoint via HTTP 1.1. After the connection is established the data can be send via TCP/IP.

NTRIP Caster:

The NTRIP Caster is in general a HTTP server and acts, as already described, as a broadcaster integrated between the data sources (NTRIP Server) and the data receiver (the NTRIP Clients). The NTRIP Caster receives data streams from NTRIP Servers (generated by NTRIP Sources called Mount Points). Mount Point are the base stations such as Mulgrave, Cowan, Bathurst in Sydnet. The Caster also handles, passwords, billing and access for the CORS system.

2.53   Mirror Mode (As developed by Utilserver)

When in Direct IP mode the reference station is generally near the server. In mirror mode the reference station is separate to server. As shown in Figure 2.6, the method allows the base station to broadcast its corrections over the internet and the server can be in another country and still host multiple users.

As this is beyond the scope of this project, I will not explain this method any further.
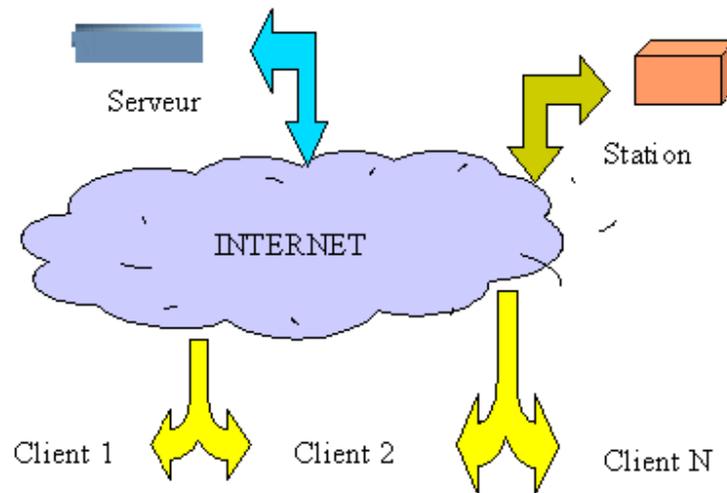
Figure 2.6 - Mirror Mode (Source: Utilserver Reference Manual, v1.7.0)

2.6   Internet Bandwidth

The term Bandwidth is often used to describe the amount of data that can be transferred to or from the website or server, measured in bytes transferred over a prescribed period of time.

Speed, for most sites, depends on the site being accessed and is related to the site's internet connection method, site capacity, number of concurrent users and data transmission load There is wide variability in rates among differing sites. One can often identify sites that are consistently fast in responding and others that are consistently sluggish.

Speed also depends on the Internet network performance. Several well-known network slowdowns have occurred when Internet traffic was unusually high due to unusual news events. The efficiency also varies with the network loading throughout the day.
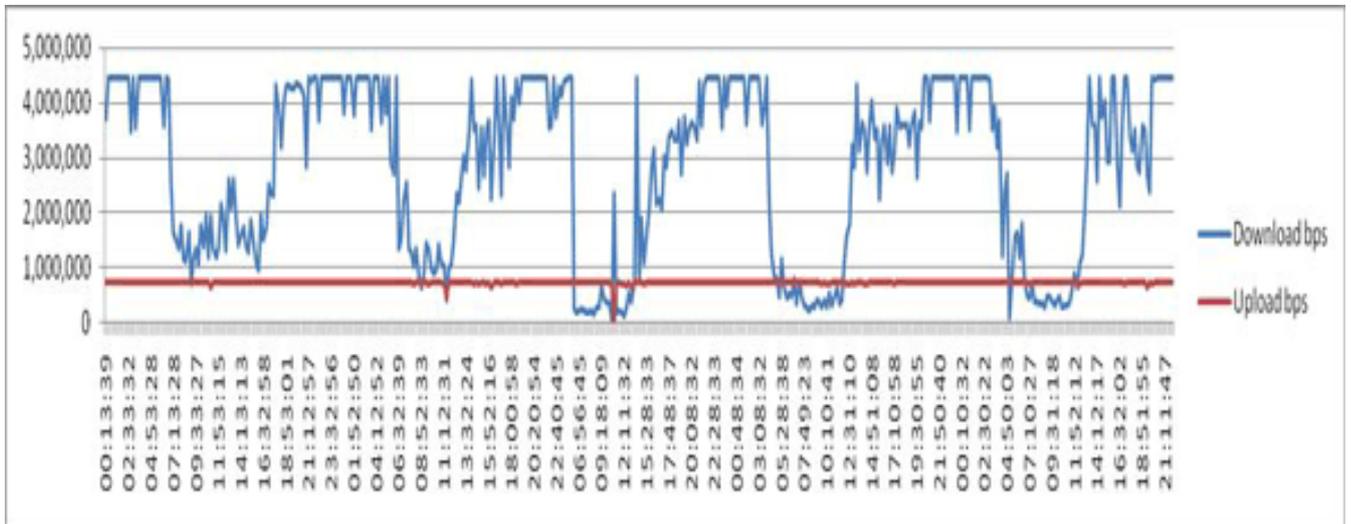
Figure 2.7 – Internet Congestion patterns - day versus night

(Source: http://www.myconnectionserver.com/whitepapers/solve_connection_speed_problems.html)

Figure 2.7, shows a number of speed tests extracted from the MySpeed Server database for a single user connection. This data shows a clear drop in service during daytime hours, which then improves towards evening and returns to normal during the night. This type of pattern is typical of congestion, and would be an issue for your Internet Service Provider to address.

The Internet also assigns a route that passes from computer to computer to connect you with your destination site. This route varies, depending on availability of the intermediate connecting sites. This route variation also contributes to speed variability.

 Finally, there is the ISP's contribution to speed variability. The ISP has a bandwidth limit depending on its system capacity and Internet connections. These bandwidth-dependent variations here have all the dependencies outlined above, except that the route between your computer and the ISP is usually predetermined.

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2.7   Receiving correction data

There are currently two possibilities of sending correction data. It can be handled directly from a single reference station or all observations from several reference stations used in a network can be forwarded to a central unit (server) for further processing before broadcast.

The user gets access to the internet using a modem (mobile phone) via a defined client software that streams DGPS correction data from a server to the mobile GPS receiver. The correction data needs to be sent from the Server / PC via a wired Internet connection and then out to the rover utilizing a mobile radio network.

Users in the field have the choice to decide the technique for receiving DGPS or Real Time Kinematic (RTK) through the Internet. They include GSM, GPRS, EDGE and in future UMTS.

Two popular choices are described as follows;

− GSM (Global System for Mobile communication) is a public digital cellular network using techniques for multiplexing and using transmission band around 900 MHz. It is a worldwide standard. A GSM network can provide, besides telephony services, data communication in circuit and/or package mode. A more recent version uses an 1800 MHZ band (Europe) whereas a 1900 MHz access network is running in the United States.

−GPRS (General Packet Radio Service): is a global system for mobile communication that increases the channel speed from 9600 to 14400 bits per second (bps), adding data compression. With GPRS, mobile data transmissions can be as fast as 115000 bps using the existing GSM base station infrastructure.

The advantage of using GPRS (General Packet Radio Service) technology is that you can be connected all day, but only pay for the data that is received. Hence the operating costs are normally much lower than using "normal" mobile phone RTK links.

2.8 NTRIP / Direct IP – Research and Testing

There has been extensive field testing to check the achievable accuracy of NTRIP over conventional RTK and DGPS methods. Dammalage et al (2006) carried out observations during the period of March to May 2006 using single frequency (L1), dual frequency (L1/L2) and handheld receivers. The accuracy was compared over different baseline distances and the results are displayed in Table 2.1 below.

Table 2.1 - Comparison of the observed accuracy according to the base-line distance
(Source: Dammalage et al, 2006)

Base Line	Trimble L1 Receiver			Sokkia L1/L2 Receiver		Garmin eTrex	
	RAW	Int - DGPS	PP - DGPS	Int - RTK	Radio- RTK	RAW	Int- DGPS
5km	0.602	0.532	0.586	0.162	0.161	3.4	4.5
15km	0.819	0.621	0.496	0.152	0.160	2.1	2.1
30km	1.926	0.340	0.416	0.158	0.160	4.0	2.2
60km	1.521	0.521	0.590			4.3	2.1

The table above compares the accuracy of differential corrected observations using conventional (post-processing and radio-RTK) and NTRIP with the uncorrected observations according to the baseline distance. The results show that, with the Internet RTCM stream, all three different receivers show enhanced observation value than RAW observations and shows similar accuracy of observation with the conventional DGPS and RTK techniques (Dammalage et al, 2006).

Dammalage et al (2006) also found that the accuracy of an L1 receiver using NTRIP compared with post – processing DGPS observations was very similar. The results of both methods deviated very

slightly and that it was possible to maintain an accuracy level of 0.5m at 60km. However, with baselines of 25 – 30km and beyond, it was found that it took nearly 30 minutes for initialization. This time applies for all methods.

Pala et al (2004) conducted tests using Direct IP and NTRIP. A delayed mode test was initiated to check the percentage of ambiguities fixed within a given number epochs, the percentage of correctly fixed positions and the time required to fix a given number of ambiguities. Tests were performed over 3 distances (10m, 3km and 15km).

The 10m tests allowed them to compare GSM and GPRS connections with an Ethernet LAN. The results favoured the GPRS over the GSM connection. At 10m both the NTRIP and Direct IP method compared equally.

The tests performed at 3km and 15km showed that NTRIP remained stable compared to the Direct IP server. This is due to the automatic re-connection system of the NTRIP server. As the distances increased the time required to fix ambiguities remained constant using NTRIP.

Pala et al (2004) also compared latency of the LAN, GPRS and GSM communication methods. A latency time of 1 – 2 seconds was found with the LAN, 3 -4 seconds with GPRS and over 7 seconds with GSM. A test for latency was also compared using GPRS with NTRIP and Direct IP. Results showed that NTRIP latency times were 1 – 2 seconds more than 50% of the time.

Chen et al (2004) compared performance of GPRS and GSM to conclude that the GSM provides a more stable connection whilst the rover is moving at higher speeds. GPRS is a packet switched technology which also means that the more GPRS users connected to a base, the lower data rate is available. As GSM is a packet switched technology, the GSM data call has the same priority as a voice call and it is not limited by the GPRS capacity at the base station.

In the ProMark3 RTK White Paper 2007, Magellan tested the accuracy of the ProMark3 with different configurations and different baseline lengths. Presented in Table 2.2 are the field results obtained in an open-sky environment.

Corrections were transmitted to the rover according to two different methods:

- Radio link between ProMark3 RTK base and ProMark3 RTK rover using Magellan radio modems. Baseline was 10 m.
- GPRS connected to a Z-Max Base station through Direct IP. Baseline was 2 km. The positions computed by the ProMark3 RTK rover were compared to the same positions measured with a Z-Max and post-processed with GNSS Solutions.

Table 2.2 - Fixed Solution Results (Source: ProMark3 RTK White Paper, 2007)

Test Results	10-m baseline (Radio link used between ProMark3 base and rover)	2-km baseline (ProMark3 rover connected to Z-Max base thru Direct IP mode)
Number of trials	213	129
Horizontal bias (mm)	8 mm	5 mm
Vertical bias (mm)	6 mm	10 mm
Horizontal Standard Deviation (mm)	5 mm	8 mm
Vertical Standard Deviation (mm)	6 mm	10 mm
Reliability	99%	99%

All these tests were done in automatic mode with On-the-Fly initialization. The results were all below 10 mm with more than 99% availability showing a very good quality of the solution compared with dual-frequency post-processed GPS.

2.9   Conclusion:

Pala et al (2004) concludes that precision level obtained using the internet as a transmission medium for differential GPS depends upon different factors such as the connection system and the protocol used. It was found that the stability of NTRIP was favoured over Direct IP and that the GPRS was preferred over the GSM connection as the GPRS is priced only on the amount of data that is downloaded whilst the GSM costs are time based.

With the different tests undertaken, it is evident that GPRS with NTRIP would be a good solution for GNSS data transmission over the internet. GPS surveying normally requires static or stop and go field procedures. NTRIP would provide a more stable connection when fixing ambiguities and GPRS would be more cost efficient for data downloads.

This research project will investigate the performance of the ProMark3 using Direct IP and seek to explore the benefits of using Direct IP as against NTRIP as an alternative server.

CHAPTER 3 – EQUIPMENT CONFIGURATION & DESIGN

3.1   Introduction

The purpose of this research project is to design a portable network GNSS data stream via the Internet with the ProMark3 and Direct IP. When you choose a location for a base station, you should look to achieve the following factors such as good security, clear open sky, good electricity supply & availability of fast & reliable internet.

The aim of this chapter is to outline the procedures conducted to design a portable home/office and a field based GNSS reference station broadcasting differential corrections using Direct IP. A continuously operating base station will be erected on my office roof in a rural area and a field base station will also be designed and erected in a safe and suitable location for testing purposes.

Chapter 3 will begin with a brief introduction to the ProMark3. Separate discussions will follow on the office and field designs including procedures involved in setting up the system, the choice of Direct IP program, setup costs, any initial problems and what I did to overcome them. Both designs will conclude with discussions on other alternatives for design and implementation.

3.2   Project Background

The Magellan ProMark3 – An introduction

The Magellan Professional ProMark3 RTK GNSS is single frequency (L1), 14 channel, dual - constellation GNSS receiver.

Historically, RTK systems have used both L1 and L2. The difference between an L1 and an L1/L2 receiver lies in the number of carrier frequencies they can track. An L1 receiver tracks only one of three carrier frequencies transmitted by the GPS satellites whereas an L1/L2 receiver tracks L1, L2 and L2C carrier frequencies. Tracking three frequencies enables an L1/L2 receiver to achieve the same amount of accuracy as an L1 receiver but with less observation time and over longer baselines.

Most L1 receivers are capable of achieving an accuracy of 1cm + 1 part per million (ppm), whereas most L1/L2 receivers are capable of a 5mm + 1ppm accuracy. However, L1/L2 receivers typically cost much more than L1 receivers.

The ProMark3 RTK costs between $14,000 and $18000 AUD, depending on features and offering an economical alternative to more expensive L1/L2 RTK systems.

Figure 3.1 - ProMark3 (Source: PM3 RTK White Paper 2007)

ProMark3 RTK operates in two modes; base + rover and rover only. The rover can be connected to a real-time network through a web-enabled cell phone using Network Transmitted Real Time Corrections via Internet Protocol (NTRIP) and Direct Internet Protocol (DIP) .The second mode of RTK operation, base + rover as shown in Figure 3.1, employs a spread-spectrum radio solution that does not require a license or separate configuration integrated with ProMark3 RTK.

The ProMark3 also utilizes Satellite Based Augmentation System (SBAS) measurements which includes WAAS (*Wide Area Augmentation System*), MSAS (*MTSAT Satellite Augmentation System)* and EGNOS (European Geostationary Navigation Overlay System) in the RTK processing.

WAAS/EGNOS/MSAS as displayed in Figure 3.2, all consist of ground reference stations that monitor GPS satellite data. Master stations collect data from the reference stations and create a GPS correction message. This correction accounts for GPS satellite orbit and clock drift plus signal delays caused by the atmosphere and ionosphere. The corrected differential message is then broadcast through one of two geostationary satellites, or satellites with a fixed position over the equator. The information is compatible with the basic GPS signal structure, which means any WAAS-enabled GPS receiver can read the signal.
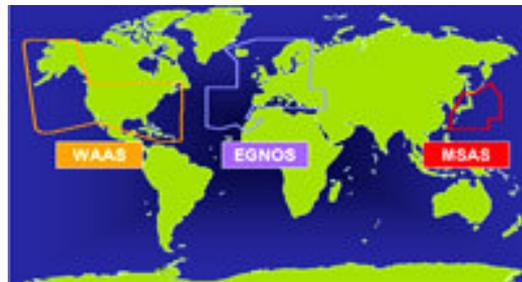
Figure 3.2 - SBAS coverage (Source Track Logs Viewed Feb.08, http://www.tracklogs.co.uk)

In Australia the ProMark3 tracks the MSAS satellites 129 and 137.

Some of the disadvantages with the PM3 compared with more expensive receivers currently on the market include,

- Long range RTK (>10km) with L1 will require a long time to initialize and may not be possible.
- Instant fix even for short baselines is not possible with L1 (single frequency).
- Partly shaded conditions can delay L1 RTK initialization times.

However the ProMark3 offers;

- Low-priced RTK system
- Small and light RTK system
- Handheld RTK system.

3.3   Design of a portable Office / Home based GNSS solution.

3.31   Antenna setup and connection to computer

The ProMark3 NAP100 Antenna was setup on the roof of my office in rural north - west Sydney. The antenna's final position was decided after placing the ProMark3 in several locations on the roof as shown in Figure 3.3 to see where it would detect the maximum amount of satellites. A Clinometer was also used to measure the angle between the antenna and the nearest tree canopy. I found that all trees were less than 10 degrees above the horizontal which would allow good reception of all available satellites.
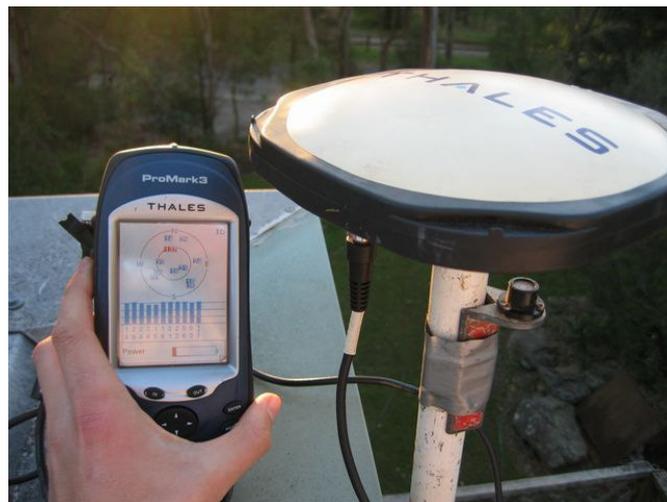
Figure 3.3 - ProMark3 base erected on office roof.

After settling on a position, an antenna mount was erected using an old prism pole and brackets secured to the wall to ensure that the mount would not move. By use of a prism pole, the antenna could be dismounted very quickly, making this design very portable.

It is very important to ensure that the mount is secure and can be accessed safely. Regular observation of its condition and monitoring of its horizontal and vertical position are also important to ensure continuous reliability of results.

After successfully erecting the antenna, I needed to run an antenna cable from the antenna to the GPS receiver. The ProMark3 comes standard with a RG58 coaxial cable 1m long as shown in this field setup in Figure 3.4.

Figure 3.4 – Typical Field setup showing ProMark3 with 1m long antenna cable.

Sagem Australiasia based in Sydney are the distributors for the ProMark3 throughout Australia. They kindly supplied me with 8m of RG58 coaxial antenna cable with a Male and Female TNC end. This cable would run down the face of the office and through the window attaching to the standard 1m cable and to the GPS receiver inside.

The ProMark3 is then connected to mains power via a power adapter to ensure it retains maximum battery power. For transfer of data, the ProMark3 uses a null modem serial cable to connect to the computer as shown in Figure 3.5. Modern computers these days have replaced serial ports with the faster USB port. If your computer does not support a serial connection then a serial to USB adapter plug is necessary to overcome this problem.

The computer used for this project is running Windows XP and connected to Telstra Bigpond ADSL2+ internet on a 1500/256kpbs plan. A backup power supply was also attached to the computer which would turn on if a black out occurred allowing enough time to shut down the computer. In rural areas electricity supply is unpredictable due to fallen trees or power disruption during inclement weather conditions.

To broadcast GPS corrections over the internet I used a freeware program called GPS3D. The particulars of this program will be discussed later in the dissertation.

3.32   The antenna cable problem and solution.

With basic understanding of how the base was put together, I needed to test the system to ensure it worked.

One of the first tests I conducted was to ensure the Promark 3 would actually detect satellites using the extension antenna cable. The ProMark3 comes standard with a 1m antenna cable and from email correspondence with Magellan in the United States and through Magellan message boards on the internet, it was unclear as to whether the antenna would work successfully using 9m of RG58 cable. Little testing or information concerning this configuration had been conducted by any users of the ProMark3.

When I finally turned on the Promark 3, it didn't detect any satellites. Sufficient time was given for it to warm up and unfortunately no result.

I consulted Sagem again who supplied me with the cable. They responded by saying that the ProMark3 was probably not powerful enough to run the antenna alone over such a long antenna cable length. They suggested an alternative solution which was to use another GPS receiver with more power connected to a GPS splitter box made by Rojone www.rojone.com.au.

Sagem supplied me with an Ashtech Dual Frequency Receiver, a GPS splitter box by Rojone and another 8m cable with female TNC ends to run from Antenna to splitter box. The standard 1m lead would still connect from the Promark 3 to the splitter box as shown in Figure 3.5 below.

Figure 3.5 – ProMark3 connected to Rojone Splitter Box and Ashtech Dual Frequency Receiver.

On the splitter box, the ProMark3 would be connected to the GPS 'blocked port' and only used for the controls onboard the GPS (i.e. To start the base station) and the Ashtech receiver would power the antenna and connect to the GPS 'through port' on the splitter box. The antenna lead would plug into the antenna port as shown above.

After connecting everything back up, I turned the system on. The ProMark3 started to detect satellites. This was a great result however not the desired configuration for the experiment. I needed to find a way of just using the ProMark3 without additional help. One of the objectives of this project was to create a GNSS solution using only the ProMark3. If other users of the ProMark3 were keen to establish their own base station, it would be nice if they didn't have to purchase another GPS to help run the system.

I decided to disconnect the Ashtech receiver leaving the ProMark 3 attached in the GPS 'blocked port'. To my surprise I was still retaining satellite signals. It wasn't until I investigated the splitter box further that I discovered it had been mislabeled. The ProMark3 was actually plugged into the GPS 'through port'.

Further research into the GPS splitter specifications revealed that the splitter box was actually passing Direct Current from the Promark3 connected to mains power, through the splitter box to the antenna to give the antenna enough power to operate efficiently.

3.33   Direct IP Program - GPSD.

With the cable problem solved I moved onto the investigation of how I was going to broadcast GPS corrections over the internet. The first thing I needed to do was find a program which would do such a thing. I found a freeware program called GPS3D through the internet at http://www.mgix.com/gps3d . GPS3D and its source code are in the public domain and freely available for download.

Within GPS3D is GPSD. GPSD is a daemon (program that runs in the background) that will monitor a serial port for messages sent by a GPS device and broadcast it on a TCP port. It actually broadcasts anything that comes in on the serial port, so you could use GPSD to do an internet broadcast of any device (i.e. GPS, an atomic clock, an acquisition device etc.)

GPSD connects to Communication Port 1 (COM1) at 19200 bauds (baud rate) and broadcasts on Transmission Control Protocol (TCP) port 2222 by default. These defaults can be changed if necessary. I couldn't get it my computer running successfully with 19200 bauds and changed it to 9600 bauds.

After downloading GPSD, it is rather simple to operate. GPSD is a command line executable program. The command prompt can be found under the Accessories tab within windows or by typing cmd in the 'run' section in windows.

Upon executing the command prompt, simply type gpsd –speed 9600 and press Enter. The program will start running and display the message as shown in Figure 3.6 below.
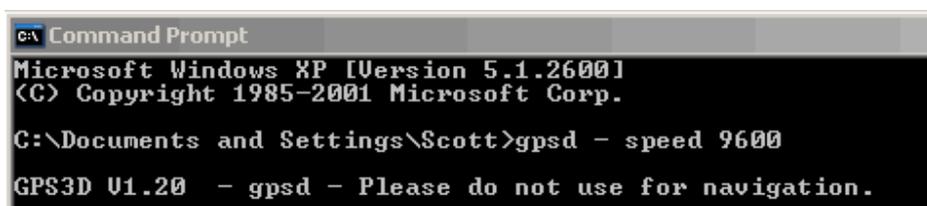
Figure 3.6- GPSD program running.

The message states "Please do not use for navigation". The developer of this program has placed this disclaimer to warn you that you must use this program at your own risk. The intention was not for any real world navigation.

With such a warning users should take extra precautions and responsibility of results achieved using the program. Additional checks can be placed including measuring onto local control to ensure that the system is giving you the correct information.

I have based all my testing using this program. The overall performance, the number of users possible at one time and comparison with another program called Utilserver, will be discussed later in the dissertation.

3.34 I.P. Address

Before we test to see that GPSD is broadcasting the GPS data, you need to find out your computers I.P. address. Several websites on the internet will tell you what your IP address is.

I used www.iplookup.com

An Internet Protocol (IP) address is a numerical identification (logical address) that is assigned to devices participating in a computer network utilizing the Internet Protocol for communication between its nodes. Your I.P. address will be four sets of numbers like this 220.101.34.96 and is normally allocated by your internet service provider.

Users who connect to the base to access data will need to know this address. The address is likely to change every time you restart your computer and should be checked every time you intend on using Direct IP. If you contact your internet service provider they may be able to assign you a Static I.P. address which won't change. Any changes to the address should be passed onto the people accessing your base especially if they access it on a regular basis.

A simple way to check that GPSD is broadcasting differential corrections to the internet is by typing the IP address of your computer and the port number 2222 into the internet browsers search bar as shown in Figure 3.7.
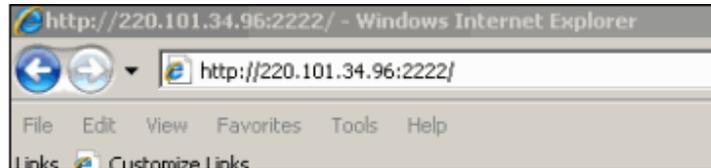
Figure 3.7– Typing the IP address and Port Number in the Internet Search Bar.

Upon pressing enter on the keyboard, the webpage will display NMEA messages as a series of complex alpha and numeric characters. This is clear indication that GPSD is receiving data from your GPS and should work successfully in the field connecting with a GPS rover.

3.35   Port Forwarding

The first time testing this method outlined in Section 3.34, it failed. I discovered that is was due to the fact that the computer was connected through a router and sharing the internet connection with another computer. I am using a NETGEAR DG834G wireless router. I am connected to this router with an Ethernet cable.

Each computer is assigned an IP address from the router. When the first computer is connected it will be given the IP address 192.168.0.2. The next computer will be given 192.168.0.3 and so on. This may be different for other router brands and so I refer only to using the NETGEAR router in this project. This IP address is not the IP address that your internet service provider supplies you with.

Once GPSD has received the GPS data, it needs to export it out through port 2222 within your firewall. When a port is open, a service is assigned to it. Software ports are numbered connections that a computer uses to sort types of network traffic. For security, by default, all ports to the internet and most LAN ports are closed so that traffic cannot flow through them.

In order to send the data to the internet you need to set up Port Forwarding within your router configuration.

What is Port Forwarding? Port Forwarding creates a `tunnel' through a firewall, allowing users on the Internet access to a service running on one of the computers on your LAN (Local Area Network), for example, a Web server. You need to be very careful when making a decision to put additional holes in your computers firewall so as not to invite any unwelcome visitors.

To setup Port Forwarding, you need to configure the router. It will differ depending on the router you are using. You need to explore the firewall settings of your router as shown in Figure 3.8 below.
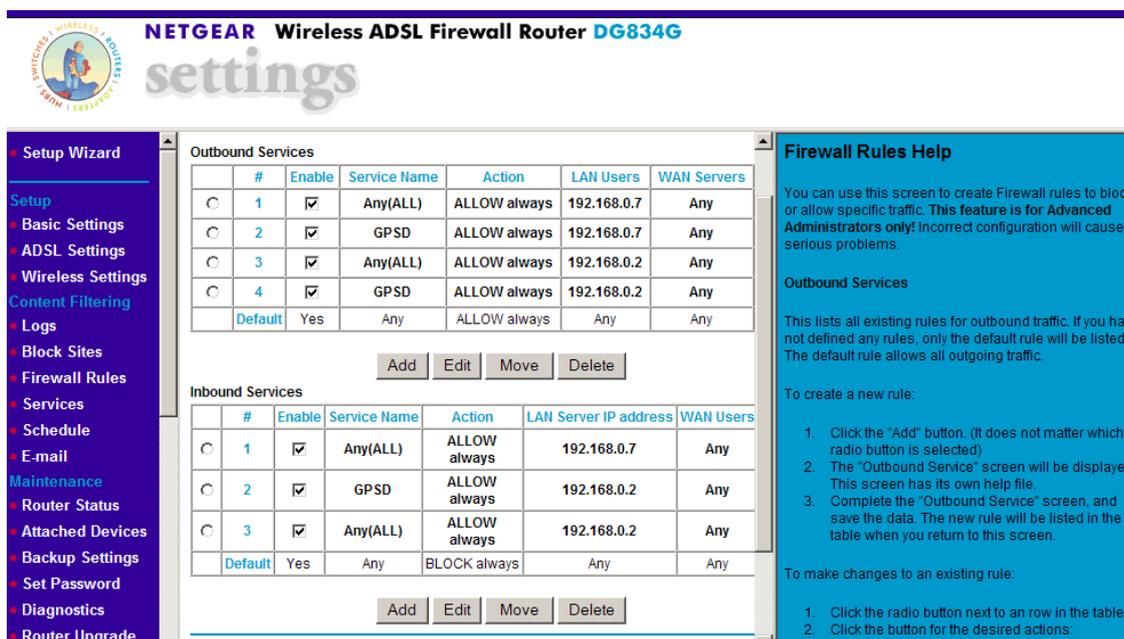
Figure 3.8– NETGEAR Router firewall settings

Upon assigning rules for the firewall, you should be able to successfully send GPS data to the internet. Simply retype the assigned IP address from your service provider followed by the port number and press enter on the keyboard. You should then see data appearing on the screen as explained earlier in Section 3.34.

It may be useful to create 3 icons on your desktop. The first icon is a link to the command prompt. You can rename it GPSD. Secondly, you can create a link to the www.iplookup.com website so that you can find out your IP address quickly. It's unlikely that the IP address will change but it's important to be able to check quickly. Lastly create a link to your IP address and port number. This 3rd link takes

you to the screen as shown in Figure 3.7 previously. By having all three icons on your desktop this will help save valuable time getting the office or field base started.

This now concludes the design for the portable office based GNSS system. A few settings within the computer and with the setup of the ProMark3 need to be achieved before the system will operate successfully.

3.4 Design of a portable field based GNSS solution.

3.41 A basic design

At the time of this project, little research has been undertaken into a portable field system using the ProMark3.

What is a portable system? You need to take the whole concept of the office base as described previously in Section 3.3 and bring it to the field. You therefore need to look at the practicality of such a system in regards to setup, security, portability, cost, usefulness and so on. I have explored the idea of bringing the office to the field and will discuss the problems I faced in detail.

What do you need for a portable system? In its simplest form you need a ProMark3 GPS with a Tripod, a laptop computer, a card table or something suitable for the computer to rest on and wireless broadband as shown in Figure 3.9.

Figure 3.9 – A basic design for a portable field GNSS network solution using the ProMark3.

The ProMark3 receiver is still connected via a null modem cable to the laptop computer which has Serial to USB adapter plug. The computer is equipped with the GPS3D software. Instead of fixed line broadband internet I am using wireless broadband. I've chosen to use a 3 Mobile Broadband Modem as shown in Figure 3.10 with a 2GB plan and speed of 1.5Mbps download and 384kbps upload.

Figure 3.10 – 3 Mobile Broadband Modem connecting to a laptop computer USB port.

3.42   Amendment to the basic design

With the basic setup as shown in Figure 3.9, the system relies entirely upon battery power. The laptop computer battery will last on average 1hr and with mobile broadband use this time may be even less because the broadband is powered by the computer. The ProMark3 will last for several hours on a fully charged battery and can retain longer time if things such as backlight controls on the unit are turned off to avoid wasting power. Other things such as not having to use the UHF radios will assist in prolonging the battery life.

To maintain constant power supply to the ProMark3 and to the computer, I will use a Projecta 12V 17Ah Sealed AGM Portable Battery as shown in Figure 3.11. Connected to this battery through the cigarette lighter socket is a 300W DC – AC power inverter which has two power outlets.

Figure 3.11 - Projecta 12V 17Ah Sealed AGM Portable Battery with 300W DC – AC power inverter

According the manufacturers specifications you can run a 13W camping lamp for 16hours. I cannot place comment on the performance of the battery, except to say that it retained enough power to operate all equipment successfully for a period of 5 hours without any complications. This could be further explored.

With a mixture of expensive equipment sitting alone for any period of time, one would wonder how safe it is. We face this situation in everyday surveying. We always leave tripods and equipment setup away from where we are working. It's all part of the job.

This is one of the concerns raised for such a system. I installed a web camera (see Figure 3.12) to capture live footage from the base. The footage could be seen either from another computer back in the office or via a web enabled mobile telephone.

The quality of the webcam, lighting and weather conditions will all play factors in the performance of picture back on the computer or phone.

Figure 3.12 – A web camera erected on a spare tripod.

As the footage is streaming live, the user will need to be prepared for any additional costs that might be charged to their wireless broadband service or viewing it from the office computer or mobile phone. The setup could be customized to update the photo every minute if desired.

I used web camera software from a website called Stickam. www.stickcam.com. They allow you to install a piece of java script code into any webpage which is linked to your webcam. As I was looking for the cheapest alternative for this system, I created a blog website. I called the website ProMark3 Security www.promark3security.blogspot.com as shown in Figure 3.13. Unscheduled outages on the website, program upgrades and website problems are all concerns associated with this and therefore 100% reliability cannot be guaranteed.
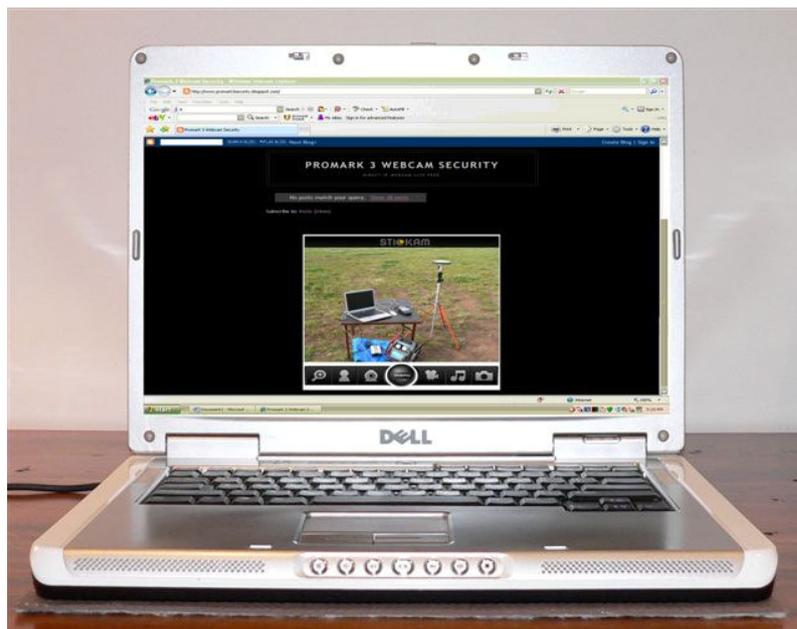
Figure 3.13 – View of portable base from webcam at office computer.

With all the pieces put together we have a portable GNSS solution (see Figure 3.14). To simplify the design I have replaced the tripod of the base with a bi-pod.
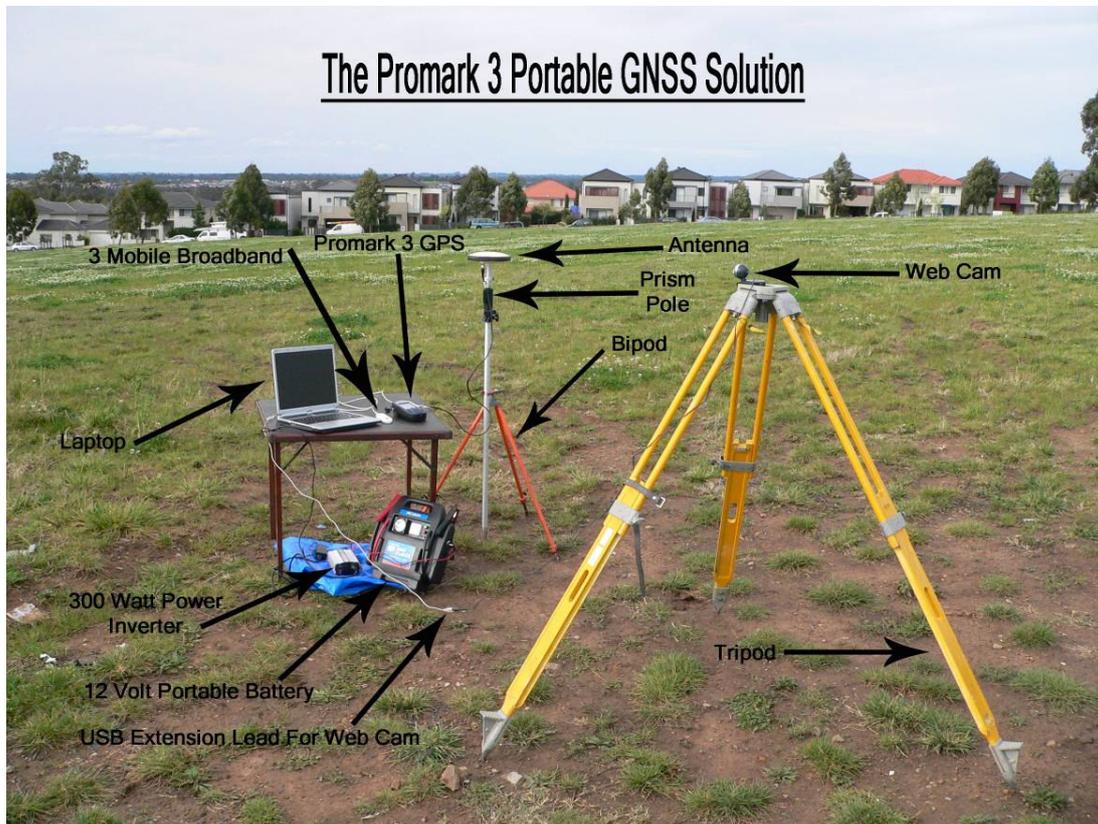
Figure 3.14 – The ProMark3 Portable GNSS Solution

Alternatives to this setup have been considered for security and wet weather conditions. With equipment ports exposed to the elements and without proper weather protection, damage could be caused to the entire system within a short period of time. Insurance of the equipment would be an absolute necessity. It's a requirement that businesses have public liability insurance to protect the public from any accidental injury from equipment.

Figure 3.15 shows another alternative to a portable solution using a car to store and protect the equipment. With the use of the extension antenna cable and splitter box as shown in the office base system, you could setup the computer, battery, ProMark3 and webcam inside the car.
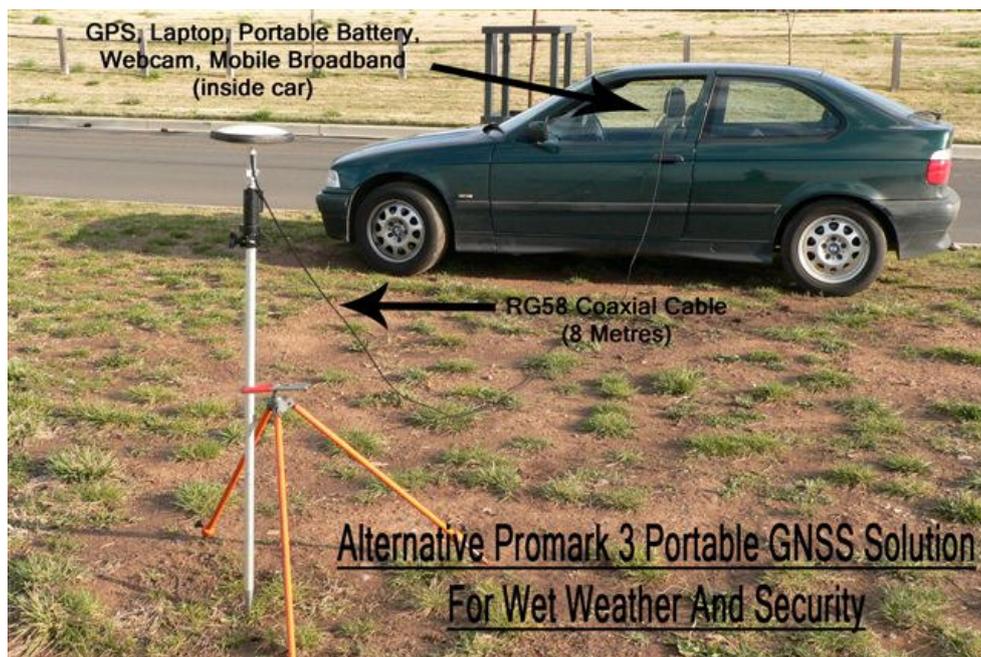
Figure 3.15 – An alternative Promark3 Portable GNSS Solution.

The gear would be protected against the elements including rain however heat may affect the gear inside. Potential trip hazards could also be avoided if suitable barriers, witches hats or signs be erected near the gear. As mentioned earlier, public liability insurance would be essential in this situation.
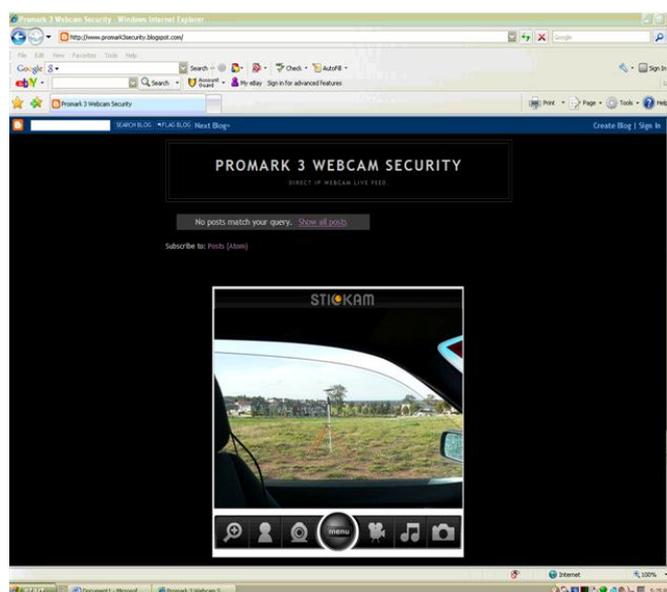
Figure 3.16 – Webcam security from within a car.

Figure 3.16 shows the webcam footage from within the showing that it is possible to erect the base out of the elements.

This concludes the design for the portable field GNSS solution for the ProMark3. Security, power and protection all play major roles in the effectiveness of the setup. Reducing the amount of gear needed to setup the system will assist in its portability. Possible solutions could be the use of a Pocket PC with internet capability to receive the correction data and broadcast it to the internet. The use of Bluetooth technology to transmit the corrections back to a computer inside a car may also help with security and hazards. Additional accessories of the ProMark3 include a magnetic car mount to erect the antenna to a car or metal surface. This could be used for either base in the field or office. You could mount the antenna on a car, have your gear inside and post process the location of the base afterwards or alternatively before you start surveying.

3.5   Connecting the ProMark3 to the Internet and Direct IP

As discussed earlier, the use of the 0.5 watt conventional UHF radio has its limitations with the ProMark3. This is the main focus point of this research project. The ProMark3 has a limited working range of about 300 - 700m in built up urban areas and up to 1.5km for open areas in line of sight conditions. Third party 2 watt UHF radios can improve the range of the ProMark3 however I will not be testing this in my research project.

The concept of Direct IP involves the use of a mobile telephone with Bluetooth capability connected to the ProMark3 rover a seen in Figure 3.17. The mobile telephone acts as a modem connecting the rover to the internet.

Figure 3.17 – ProMark3 & Web enabled mobile phone.

The rover can then connect to the base who is broadcasting its position over the internet. As long as retain your telephone signal, you will retain a connection to the base.

This allows a greater working range between the base and the rover. The mobile phone can operate within range of any telephone tower. There are more and more towers being erected every day making it very easy to access data over the internet almost anywhere.

To establish a connection you must have a mobile telephone capable of connecting to the internet. I am using a Samsung SGH501 mobile with Telstra Wireless Broadband 3G.

Internet access comes with the phone plan. Associated costs with this are discussed later in Chapter 6 Section 6.5.

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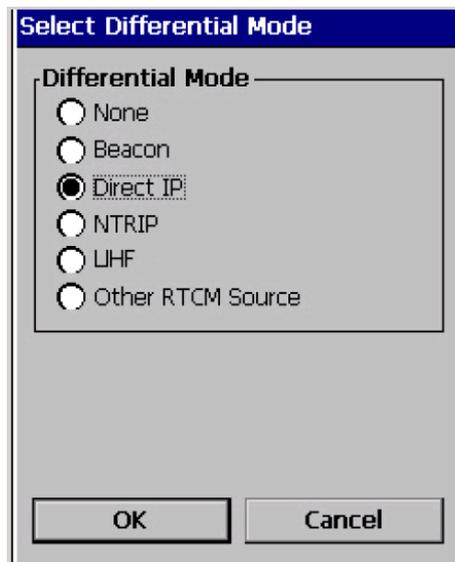
Figure 3.18 – Selecting Direct IP on the ProMark3 (Source: ProMark3 RTK reference manual 2007)

On the ProMark3 you need to select the differential mode. See Figure 3.18. Instead of using UHF, select Direct IP. The next step is to pair the GPS with the mobile phone using Bluetooth. Upon establishing your Bluetooth connection you can use the mobile phone as an internet modem. Most Bluetooth devices will work up to 10m successfully which means you can leave the mobile in your pocket or field bag as you work.

You need to dial a special number within the ProMark3 which allows the phone to act like a modem. Some of the new GPS receivers have mobile internet technology built inside, making the use of a separate mobile phone unnecessary and in the long term reducing costs. The ProMark3 does not have this capability. Having the external phone does however, provide the advantage of being able to make telephone calls whilst using Direct IP.

For Telstra you dial the number *99**1*1#. You can use the mobile phone and browse the internet without dialing this special number but to use the phone as a modem whether you are connecting to a computer or the Promark3, you will need to dial it. It can be preset into the ProMark3 which will make connecting to the internet quicker.

Once connected to the internet, the ProMark3 establishes a connection to the base station. Before leaving the base to begin work it is essential that you write down the IP address of the computer and the port number. These values can be pre-loaded in the GPS before leaving the office (See Figure 3.19) especially if you are using the same base over and over again, which will save you valuable field time.
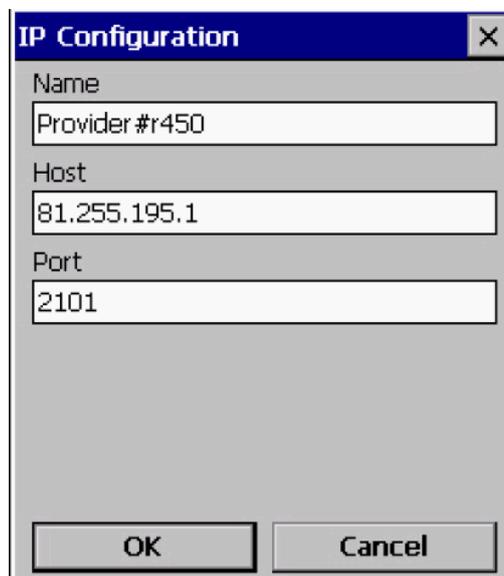
Figure 3.19 – ProMark3 IP Configuration (Source: ProMark3 RTK reference manual 2007)

After ensuring the base details are correct, it is as simple as pressing connect and watching the rover receive packets of data. Connection to the reference station will happen almost straight away if the reference station and ProMark3 rover are operating properly. See Figure 3.20.

If the rover does not connect to the base an error message is displayed and it could be one of several reasons;

- The IP Address and Port Number pre-loaded in the rover are incorrect.
- The batteries are low on the mobile phone.
- The telephone may be out of the telephone service area and could be roaming and therefore connection speed to the internet could be slow.
- The telephone has dialed the wrong number to connect to the internet. Some service providers such as 3 mobile and Optus dial *99# to use the phone as a modem.
- The reference station computer could be down or GPSD may have stopped working. This can be a real problem especially if you are trying to work greater than 10km away from the base. It is absolutely essential that you check before you leave, that the base is operating correctly or make sure you have a trained person in the office that can rectify the problem.
- If you have to place the rover down for a minute, make sure you leave the mobile phone nearby. If you walk off with the mobile in your pocket, you will lose the connection with the base.
- Other factors that may prevent connection to the reference station include, the computer battery, wireless internet problems, or the ProMark3 malfunctioning at the base end.

It is therefore important you double check all connections prior to leaving the base. A checklist may be a useful tool.

Figure 3.20 – ProMark3 connected to Base Station (Source: ProMark3 RTK reference manual 2007)

When you have successfully connected to the base you will need to execute an initialization procedure to establish a Fixed Solution with the base. In the meantime the ProMark3 will be in a Float Solution maintaining sub-metre accuracy. In a Float Solution your position will improve the longer you leave it. The results of Fixed and Float Solutions will be discussed later in Chapter 5.

3.6   Conclusion

This now concludes Chapter 3, which described the design an office and field base portable GNSS solution using the ProMark3 and Direct IP. The portability of the designs will allow the user to take the system wherever they need to work. This may be office to office or field to field. Chapter 4 will discuss methods used to test Direct IP with both bases. Range, Repeatability and times to achieve a fixed solution at certain distances will be measured to help draw conclusions on the ProMark3's performance to assess whether Direct IP does improve the range capabilities of this single frequency receiver.

CHAPTER 4   METHOD

4.1   Introduction

The ProMark3 has a limited working range using UHF radios. The purpose of this research is to prove that using Direct IP as an alternative method for communication will improve the performance of the ProMark3.

The aim of the testing will be to see that both portable base stations created in Chapter 3 work efficiently per their design. They will be initially tested on a short baseline. The baseline would be setup using a total station, level and ProMark3. A longer baseline will also be created with a Static GPS survey and adjusted using post processing techniques.

I will test the working range of the ProMark3, the length of time it takes to achieve a fixed solution, the accuracy and the repeatability of position by revisiting each station within the baseline over 3 separate days. Other tests include observing the performance of the ProMark3 in a Float solution connecting the rover to existing CORS such as Sydnet. Using my field base as the rover position, I will test several stations up to a range of about 160km. I will also check the performance by observing to my portable field base from approximately the same distance away in a separate exercise to see whether Direct IP or NTRIP differ in performance.

4.2   Initial Testing

My office is located on 5 acres, in rural north - west Sydney, only 20m above sea level.
The initial plan was to setup the office base and field base within a short distance of one another on the property. Should I encounter a problem, I could easily attend either base to fix it. I would also setup a small testing baseline nearby and then have half a dozen known survey marks at various distances to use as test stations.

I am using a 3 wireless broadband modem, to connect my field base to the internet. Searching on 3's website www.three.com.au you can find out whether you have good reception in your chosen area. My

location was out of 3's zone. I would therefore be roaming and charged extra for any usage at $1.65 per mega byte. The speed of the internet would also be reduced because of however I didn't see that as being a problem at the time.

The initial testing using the 3 mobile broadband with the portable field base, showed very poor performance out of the 3 zone as shown in Table 4.1. The internet signal was so low that the rover could not get a fixed solution even at 35m. The download speed of the internet was reduced to 236kbps as opposed to 1.5 Mbps in a 3 zone. I also tried using the office wireless broadband through the wireless router. The signal was also very low and no result achieved.

Internet Source connected to Laptop	Reception	Time To Fix at 36m (>5mins = Stopped)
3 Mobile Broadband Modem Speed Roaming 236kbps	Low	Stopped
Wireless Router at 50m Speed 54Mbps	Low	Stopped

Table 4.1 Wireless Internet Performance out of the available internet zone.

The test was then repeated using the UHF radios. The Rover was able to get a fixed solution in 2 minutes 29 seconds which proved that poor internet reception at the base would affect my results. The location for the portable field base was not practical for testing purposes and so I needed to re-think my base location and the position of my testing stations.

I chose a park opposite my place for the location of my field base. It would be safe for testing and easy to setup and within 3's broadband zone giving me maximum speed for the internet. The office base would still remain as per the initial plan using fixed line internet. This created a baseline distance of approximately 16km between both the office and field bases.

4.3   The Test Range

Before establishing the sites of the test range, I began some initial testing with Direct IP using the Office Base. Even though the recommended working distance for RTK using a L1 receiver is limited to no more than 10km, I still wanted to explore how far I could go and what time it took to achieve a fixed solution. I needed to be sure that the ProMark3 would obtain a fix to a distance of at least 16km so that I could later measure to all test stations from both bases.

Using local survey marks I conducted a static survey to fix the position of the office roof. After calculating adjusted co-ordinates for the base I began measuring to various survey marks with known coordinates at 2km, 7km, 11km and finally to a mark 17km away (See Figure 4.2).

Using the Spatial Information Exchange Viewer (SIX) from the Department of Lands N.S.W, I was able to locate other coordinated survey marks. These marks were chosen for their good sky visibility as shown in Figure 4.1 and also for their positional accuracy. It was very hard to find survey marks that would meet all of these requirements. Some marks only had positional accuracy and some only height accuracy. It was important to find a mark that had both height and co-ordinates. Travelling to and from the marks was also very time consuming. They were not along a highway or a main road making it easy to get from one to the other. This factor needed to be considered if I was setup a suitable test range.

Figure 4.1 – ProMark3 Rover setup on a Permanent Mark 67533 buried in the ground.

Station	Distance from Base	No of Satellites	Time to Fix Solution	Accuracy East	Accuracy North	Accuracy Height
SSM 81714	2km	10	2 m 19 s	-0.021	-0.017	0.032
PM 67533	7.2km	11	3 m 33 s	-0.026	-0.013	0.010
PM 44130	11km	9	7 m 57 s	-0.035	-0.011	-0.180
PM74697	17km	11	25 m 58 s	-0.087	-0.007	-0.192

Table 4.2 – Initial Testing using the ProMark3 and Direct IP.

Table 4.2 shows the positional accuracy achieved with different satellite geometry using Direct IP on known survey marks. After achieving a fixed solution on the survey mark, I logged its position for 1 minute. The results are quite impressive. I was able to measure further than the UHF radios would allow going beyond the recommended limit of 10km for RTK surveying. The accuracy would be sufficient for basic detail especially data collection for G.I.S purposes. With this result, the testing regime would work as planned.

Figure 4.2 – ProMark3 Fixed at 17km.

The time taken to fix at 17km is of concern. For most practical purposes it would take too long to complete your survey if you were lose lock and have to initialize again. The distance between the field and office base was 16km and so I was happy to not go beyond that distance for my baseline.

As I had settled on using the office base and the park near my home as the field base, I needed to establish a baseline between both locations which would be easy to travel to, accessible, safe for equipment and offer good sky visibility. Finding enough marks to satisfy all requirements became very difficult so I decided to place my own marks and coordinate them with a static survey using local marks and Sydnet Stations. The final coordinates were on Map Grid of Australia (M.G.A) and the heights were ellipsoid heights using the WGS84 ellipsoid.

The baseline consisted of 10 marks in total .They were chosen carefully so that both the office and field base could measure to the same marks and retaining similar distances. I could compare the Range, TTF (Time to Fix) and observe the co-ordinates for, repeatability & accuracy. The results of these tests are detailed later in Chapter 5.

4.4 Static survey

The static survey conducted for this research project followed guidelines setout in the Inter-Governmental Committee on Surveying and Mapping, Standards and Practices for Control Surveys (SP1) Version 1.7 September, 2007. Local survey marks & Sydnet Stations were used in the adjustment.

Single frequency receivers can still satisfy Class A, B, C, D etc. requirements up to 20-odd km, but need an increasing number of hours of observation if the higher Classes of survey or longer baselines are observed (SP1, 2007). Both the office and field base carried out satellite observations for 8 hours whilst the individual stations were observed for 30mins. A least squares adjustment of the network, both minimally constrained and fully constrained were conducted with results showing a 95% positional error of 0.002E x 0.002N x 0.002Ht. The final co-ordinates of the stations are shown in Table 4.3.

Pt No.	Easting	Northing	Ellipsoid Height	Description	Photo
1	308222.310	6267731.853	79.456	Field Base / Bolt in Dirt Open Sky / On Hill	
2	308467.077	6267904.324	70.501	Nail in Path/ Open Sky	
3	308423.487	6267996.940	69.394	Nail in Path Open Sky	
4	308016.259	6269556.643	74.326	Nail in Path Open sky Hill to south	
5	305793.384	6272232.834	72.506	Nail in Path Open Sky	
6	305273.006	6277825.988	62.307	Bolt in Bitumen Open sky	
7	306046.518	6281625.165	70.538	PM 66530 Trees to West	
8	306807.488	6283398.564	43.447	Nail in Rock Trees to East	
9	306774.957	6283413.596	43.984	Nail In Rock Trees to East	
10	306725.681	6283435.174	49.082	Fixed Base on Roof Open Sky	

Table 4.3– Adjusted Control Stations for Direct IP testing.

4.5 Absolute verses Relative Measurement

To ensure that the ProMark3 was working efficiently with Direct IP, I setup two short baselines near the office and field bases. At the office base two marks were placed in rock. They were Stations 8 & 9 as shown in Figure 4.3 and approximately 50m away from the base.

For the field base, Stations 2 & 3 were nails placed in a concrete path 102m apart as shown in Figure 4.4 and approximately 300m from the portable base. The short baselines were coordinated within the static survey of all the marks, as well being leveled and distances measured with a total station.
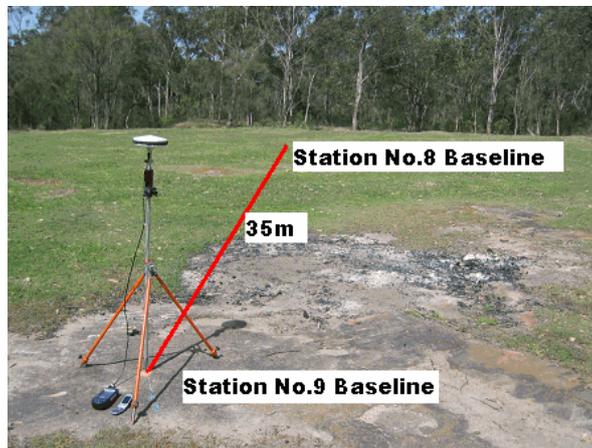
Figure 4.3 – Short Baseline at Office Base - Two nails in rock placed near office base 35m apart.
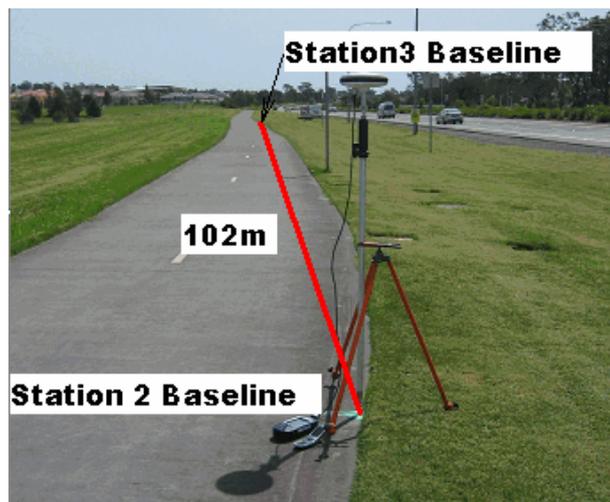
Figure 4.4 – Short Baseline at Field Base - Two nails in concrete path near portable base 102m apart

The results shown in Table 4.4 compare the observed co-ordinates using Direct IP with adjusted coordinates in the static survey. The coordinates displayed are the last 3 decimals places. The results show good agreement with the adjusted coordinates.

Station No.	Base Location	Dist. from Base (m)	No. of Satellites	Adjusted Easting	Adjusted Northing	Adjusted Height	Observed Easting DIP	Observed Northing DIP	Observed Height DIP
2	Field	300m	10	.077	.324	.501	.081	.333	.507
3	Field	400m	10	.487	.940	.394	.496	.940	.393
8	Office	88m	10	.488	.564	.447	.489	.555	.417
9	Office	53m	10	.957	.596	.984	.960	.600	.984

Table 4.4 – Comparison of coordinates on baselines for Office and Field bases.

Station No.	Base Location	No. of Satellites	Distance By Total Station	Distance By Static Survey	Observed Distance DIP	Height Difference by Level	Height Difference By Static Survey	Observed Level Difference DIP
2	Field	10						
3	Field	10	102.353	102.361	102.351	1.104	1.107	1.114
8	Office	10						
9	Office	10	35.834	35.836	35.840	0.538	0.534	0.567

Table 4.5 – Comparison of observations made with Direct IP and with Total Station and Level.

Table 4.5 compares distances and levels obtained with Direct IP, Level and Total Station. This is a clear indication that the Direct IP program GPSD is operating correctly with the ProMark3 and producing results which would be accurate enough to conduct detail survey work and data collection.

4.6   Test Conditions and Procedures

Due to the enormity of the experiment, testing took several weeks.

Below is the order of tests undertaken using both bases to test all survey marks.

1.   Connect to Base – Time taken to do this.

2.   After 5 minutes of being connected to base in a float solution, observe co-ordinates of the station.

3.   Initialize GPS using the Static Initialization method (3 times)

4.   Book TTF (Time to Fix), the number of satellites at beginning of initialization, the number of satellites when initialization was fixed and include the number of SBAS (Satellite Broadcast Augmentation System, Geo-stationary Satellites).

5.   After fixed solution, log point for 15 seconds and book Easting, Northing, Ellipsoid Height and Age of Correction.

6.   Initialize GPS using the Known Point Initialization method (3 times)

7.   Repeat booking method for Known Point Observation.

8.   Repeat Process on 3 different days to test repeatability.

Before testing took place, I used the Mission Planning feature of Magellan's GNSS solution software, to find out what time of day offered the best satellite coverage and geometry. The ProMark3 tracks GPS satellites as well as the 2 SBAS satellites 129 & 137. I planned the measurement around 10 satellites with 8 satellites being the minimum and 14 the maximum. The elevation cutoff was set to 10 degrees. With the mission plan in place I could begin observing the stations.

Data was logged onboard the ProMark3 and written down on field sheets designed for the experiment. With the repetitive observations necessary, the ProMark3 was detached from the antenna in order to lose lock with the base. It was also turned off completely when using the Known Point initialization method, to measure the Time to Fix.

Data was entered into a spreadsheet and graphed, comparing all procedures 1 – 8. The results are outlined Chapter 5 of the dissertation.

4.7 Range Testing in Float Solution

The Magellan ProMark3 White Paper 2007 suggests that the ProMark3 can achieve sub-metre accuracy in a Float Solution, over a large distance as shown in Figure 4.5.
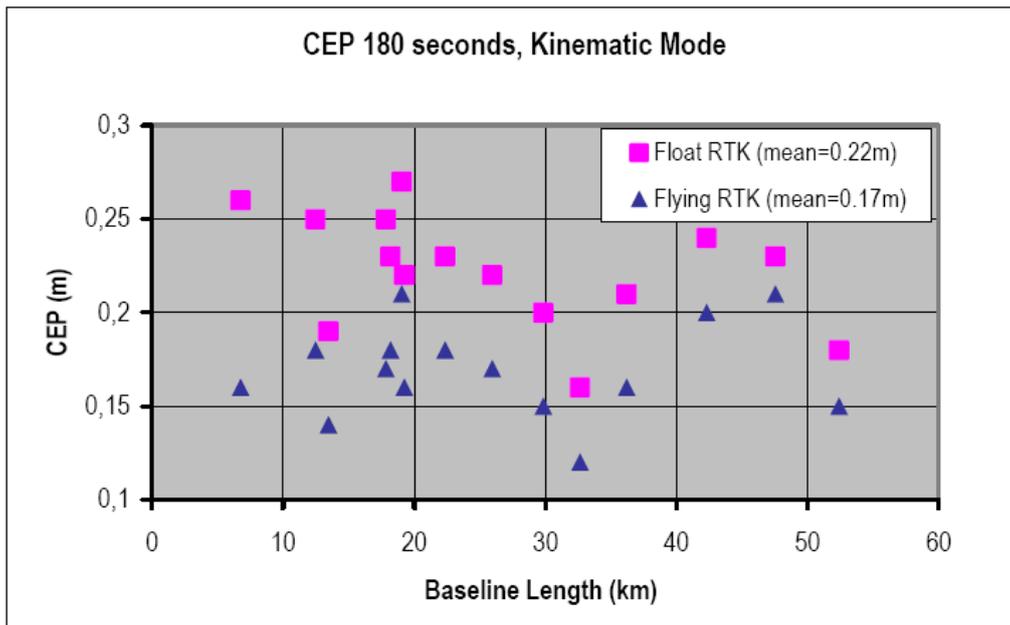
Figure 4.5 – Float performance of ProMark3 in RTK mode
(Source: ProMark3 RTK White Paper 2007)

Using my field base as the rover position, I tested the float performance against several Sydnet CORS stations up to a distance of about 160km. The ProMark3 could not achieve a fixed solution any further than the 17km that I tested earlier.

4.8 Battery performance affecting the Promark 3.

Tests will be made to see if the performance of the ProMark3 is affected when the battery in either the telephone or GPS is low. As the antenna requires power, the time to fix may be affected.
I will test this theory against a short and long baseline.

4.9 Internet speed.

Testing will be conducted to see whether internet speed affects the time taken to achieve a fixed solution. Initial testing of the portable base outside the broadband zone showed very poor results. Results of this test will be discussed in Chapter 5.

4.10 Conclusion

Chapter 4 has described the testing procedure involved in measuring the performance of the ProMark3 with Direct IP. This makes up the 3rd Objective of the research project as noted in Chapter 1 Section 1.22 Objectives.

"Establish a robust testing regime for accuracy, reliability, range, repeatability, efficiency, capacity, cost and latency of the ProMark3 receiver using Direct IP including its application to conventional survey operations"

Chapter 5 will graphically display the results and seek to answer the questions set forth in this chapter.

CHAPTER 5 – ANALYSIS OF RESULTS

5.1   Introduction

As discussed in the previous chapter, a rigorous testing regime was designed and conducted over a 16km baseline on different days and with different configurations for both the office and field bases.

The aim and purpose of Chapter 5 is to collate, analyze and display the results obtained from the testing regime and to draw conclusions from the information which will be discussed later in Chapter 6.

This chapter is broken into 8 sections, graphically displaying the results, covering the Time to achieve a fixed solution using Static and Known Point Initialization, Repeatability of Horizontal Position measuring to the individual baseline stations over 3 different days, difference in elevation at each station, Float Solution performance of distances greater than 20km, discussion about Age / Latency and time taken to connect to base, discussion on the Battery performance and finally Internet Speed performance.

5.2   Static and Known Point - Time to Fix

In order to measure points with cm precision, it is necessary to establish a fixed solution between the Base and Rover using a initialization procedure.

Using both bases, observations were compiled and averaged to show the performance of the ProMark3 at certain distances ranging from 0.1km – 17km. The time taken to achieve a fixed solution was measured using different satellite configurations. Three different initialization methods were used on the ProMark3 including, Static Initialization, Known Point Initialization from a cold start and Known Point after losing lock.

The results are displayed in Figures 5.1 – 5.7 with the left of the graph representing the time in seconds to achieve a fixed solution. The amount of satellites observed during a test period, are shown on the bottom of the graph.
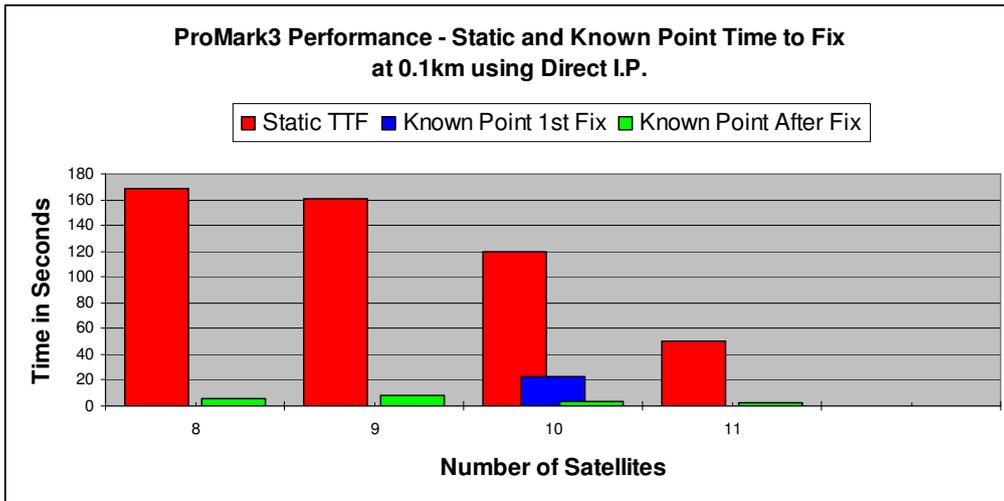
Figure 5.1 – TTF at 0.1km

Figure 5.1 shows the average time taken to achieve a fixed solution at 0.1km using 3 different initialization methods and averaged from both base stations. As the number of satellites increased the time to fix a solution reduced. The time did not exceed 3 minutes for the static method with the best result being 50 seconds for 11 satellites.

Known Point initialization was tested on initial start up of the ProMark3 and also after losing lock. Results show that the time taken to achieve the first fix was less than 30 seconds. After losing lock, fix was regained within 10 seconds of all satellite configurations.
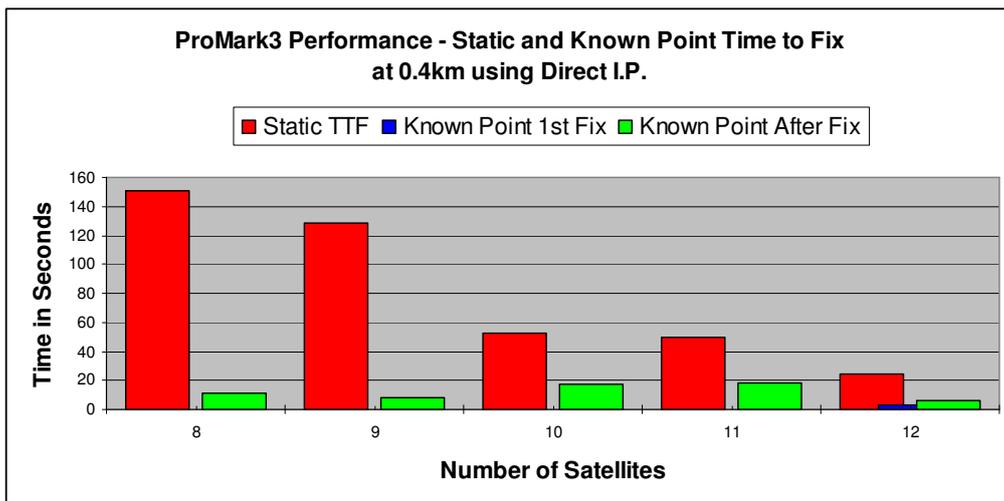
Figure 5.2 – TTF at 0.4km

Figure 5.2 shows the average time taken to achieve a fixed solution at 0.4km using 3 different initialization methods and averaged from both base stations. As the number of satellites increased the time to fix a solution reduced. The time did not exceed 2.5 minutes for the static method with the best result being less than 40 seconds with 12 satellites.

Known Point initialization was tested on initial start up of the ProMark3 and also after losing lock. Results show that the time taken to achieve the first fix was less than 20 seconds. After losing lock, fix was regained within 20 seconds of all satellite configurations.
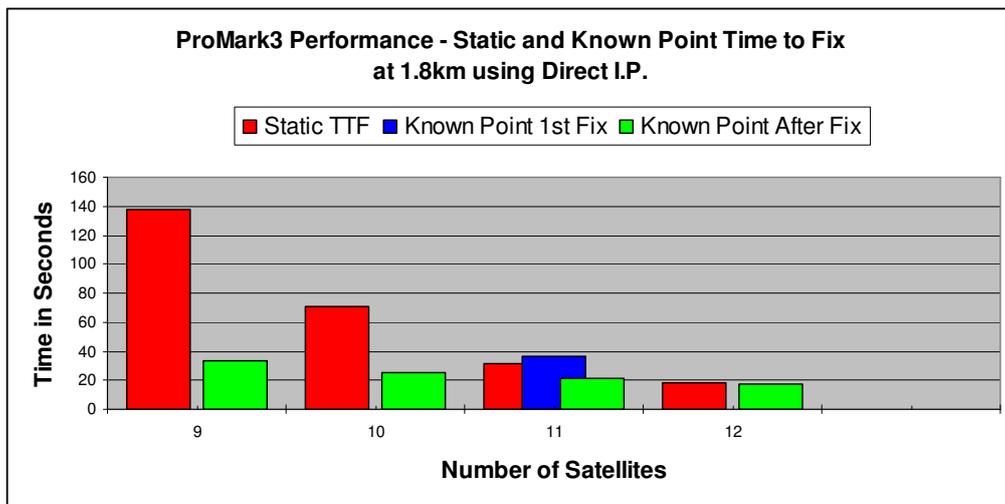
Figure 5.3 – TTF at 1.8km

Figure 5.3 shows the average time taken to achieve a fixed solution at 1.8km using 3 different initialization methods and averaged from both base stations. As the number of satellites increased the time to fix a solution reduced. The time did not exceed 2.5 minutes for the static method with the best result being less than 20 seconds with 12 satellites.

Known Point initialization was tested on initial start up of the ProMark3 and also after losing lock. Results show that the time taken to achieve the first fix was less than 40 seconds. After losing lock, fix was regained within 30 seconds of all satellite configurations.
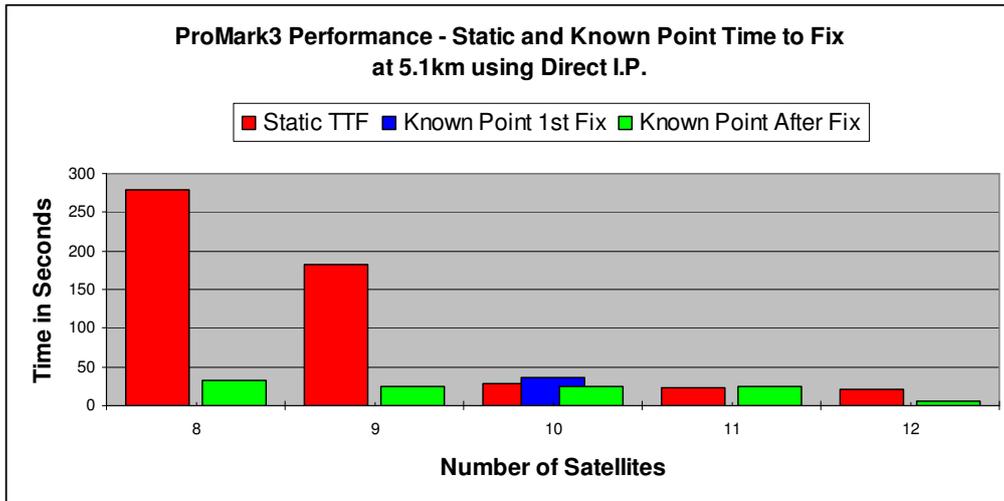
Figure 5.4 – TTF at 5.1km

Figure 5.4 shows the average time taken to achieve a fixed solution at 5.1km using 3 different initialization methods and averaged from both base stations. As the number of satellites increased the time to fix a solution reduced. Static Initialization with 8 satellites took 4.5 minutes and with 9 satellites nearly 3 minutes. The time to fix improved with 10 – 12 satellites being less than 50 seconds.

Known Point initialization was tested on initial start up of the ProMark3 and also after losing lock. Results show that the time taken to achieve the first fix was less than 40 seconds. After losing lock, fix was regained within 40 seconds with 8 satellites, and less than 20 seconds with 10 – 12 satellites.
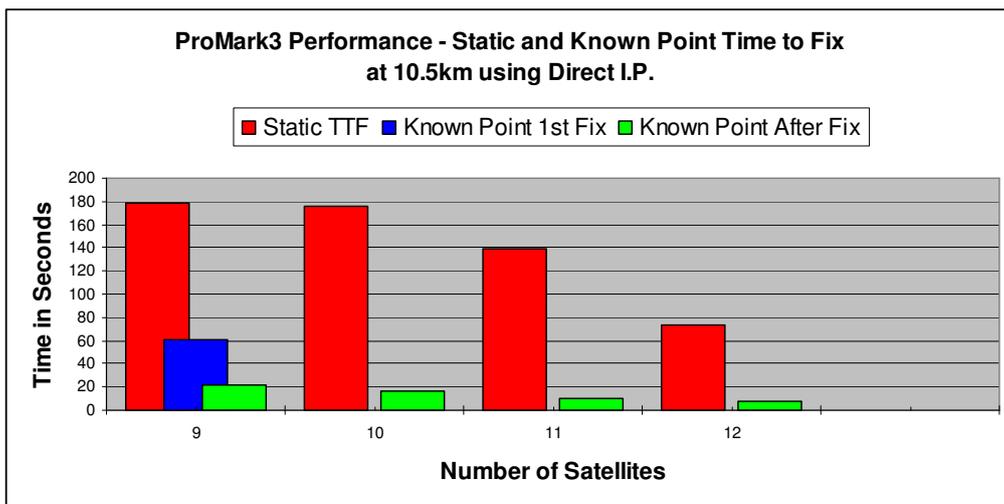
Figure 5.5 – TTF at 10.5km

Figure 5.5 shows the average time taken to achieve a fixed solution at 10.5km using 3 different initialization methods and averaged from both base stations. This exceeds the recommended limit for RTK surveying. As the number of satellites increased the time to fix a solution reduced. Static Initialization with 8 satellites took 3 minutes and with 12 satellites, a little over 60 seconds.

Known Point initialization was tested on initial start up of the ProMark3 and also after losing lock. Results show that the time taken to achieve the first fix was 60 seconds using 9 satellites. After losing lock, fix was regained within 20 seconds and less than 10 seconds with 12 satellites.

Figures 5.6 & 5.7 show two additional measurements made at 15.5km & 17km. These distances exceed the recommended limit for RTK surveying. The further away from the base you measure the longer it will take to achieve a fixed solution. For practical purposes, fixed solution testing did not exceed 17km.
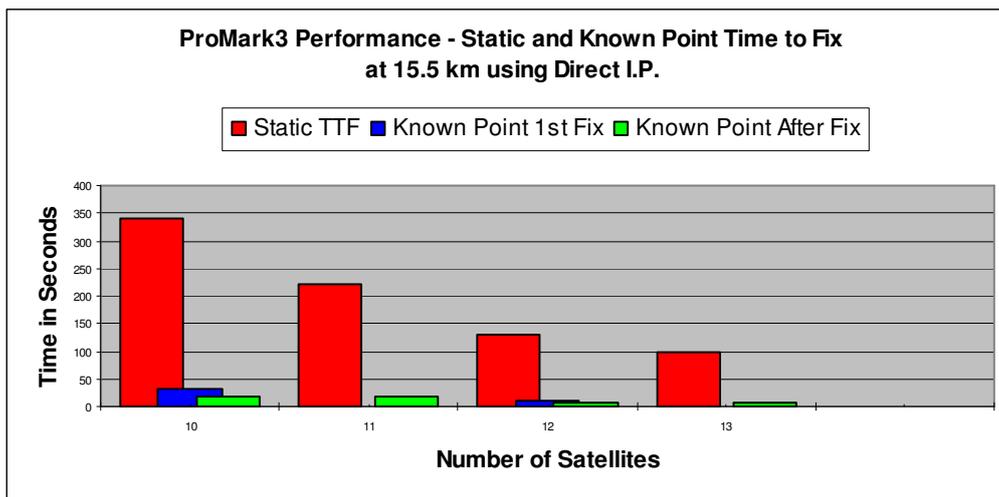
Figure 5.6 – TTF at 15.5km

Figure 5.6 shows the average time taken to achieve a fixed solution at 15.5km using 3 different initialization methods and averaged from both base stations. As explained before this exceeds the recommended limit for RTK surveying. As the number of satellites increased the time to fix a solution reduced. Static Initialization with 10 satellites took 5.5 minutes and with 13 satellites a little over 1.5 minutes.

Known Point initialization was tested on initial start up of the ProMark3 and also after losing lock. Results show that the time taken to achieve the first fix was less than 40 seconds using 10 satellites and

less than 20 seconds with 12 satellites. After losing lock, fix was regained within 20 seconds for all satellite configurations.
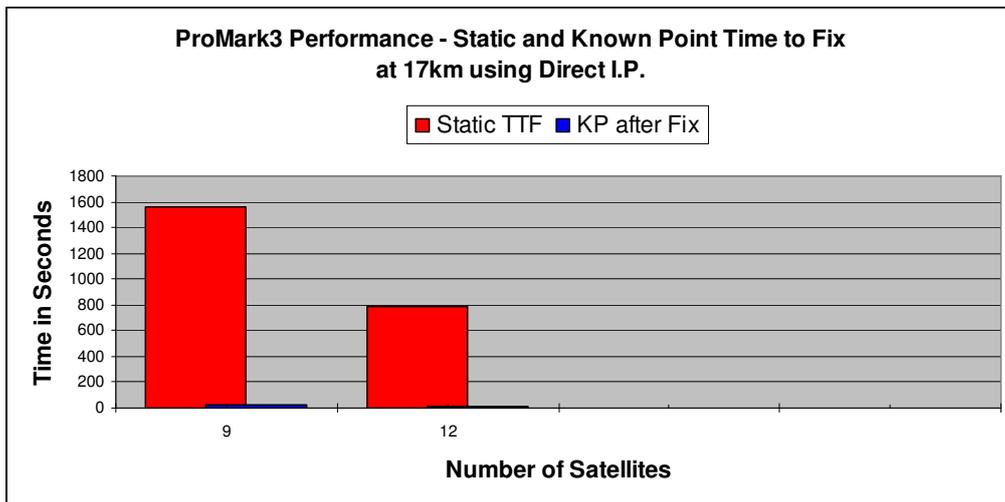
Figure 5.7 – TTF at 17km

Figure 5.7 shows the average time taken to achieve a fixed solution at 17km using only 2 different initialization methods and measured from the office base station. As explained before this exceeds the recommended limit for RTK surveying. As the number of satellites increased the time to fix a solution reduced. Static Initialization with 9 satellites took 25 minutes and with 12 satellites a little over 13 minutes.

Table 4.2 of Chapter 4, shows the positional difference of the measured mark at 17km using the Office Base. A difference of 0.087m East, 0.007m North and 0.192m Height was found. By using the true co-ordinates of the survey mark with a Known Point Initialization, 30 minutes had past without a result. Using a Known Point Initialization after losing lock, fix was regained within 20 seconds for testing using 9 satellites.

From the results displayed in section 5.2, it is evident that the time taken to achieve a fixed solution is very quick even up to 10km which is the recommended limit for RTK surveying. We will now explore the repeatability of position on the baseline stations recorded over 3 separate days.

5.3   Repeatability of Position

The ProMark3 was erected on all of the test sites 2 – 9, on 3 separate days collecting data from both bases. The baseline runs in an east west direction. The observations were compiled then average for the 3 days and graphed as shown in Figures 5.8 – 5.15. The point where the East / West and North/ South axis meets is the adjusted position for the station and will be 0,0 for the purpose of the graph.

The blue dots represent the position measured using the Portable Field Base while the pink dots represent the position using the Portable Office Base. Throughout the entire time of the project the office base was fixed in position and will be referred to as the Fixed Base in this section.

It is evident from the measurements made and graphed hereon, that all positions fell within 10 - 15mm of each other proving that using Direct IP, the repeatability of position was very reliable and sufficient for RTK purposes.
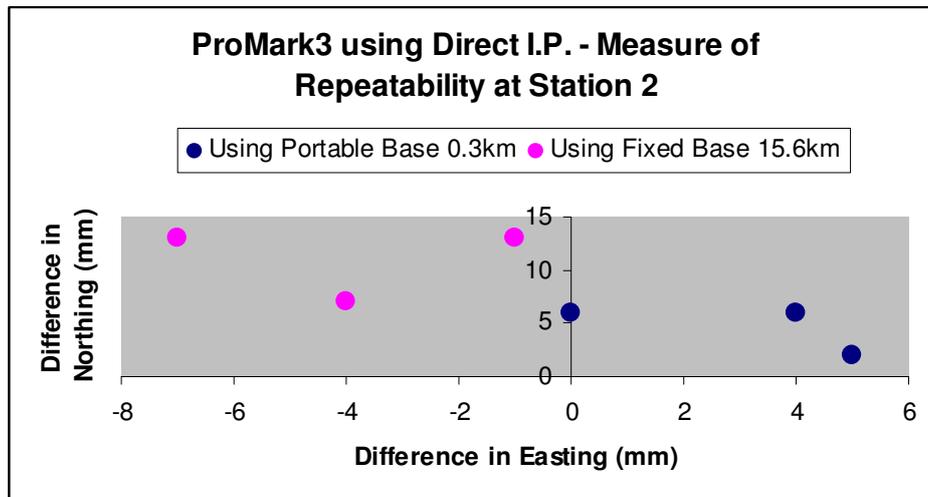
Figure 5.8 – Repeatability at Station 2

The repeatability of Station 2 is shown in Figure 5.8 above. Station 2 was measured from two bases with distances at 0.3km and 15.6km. It is evident that at 0.3km the difference in position is smaller than at 15.6km. The overall positional accuracy does not exceed 7mm in an easterly direction and less than 15mm in a northerly direction.
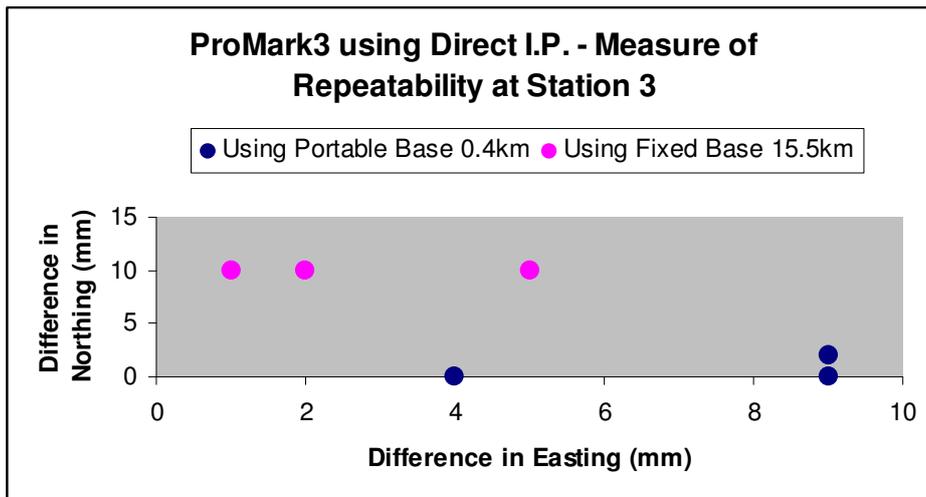
Figure 5.9 – Repeatability at Station 3

The repeatability of Station 3 is shown in Figure 5.9 above. Station 3 was measured from two bases with distances at 0.4km and 15.5km. The difference in position at 0.4km does not exceed 9mm in the east and <2mm in the north. At 15.5km positional accuracy is rather impressive with no more than 5mm in the east and 10mm in a northerly direction.
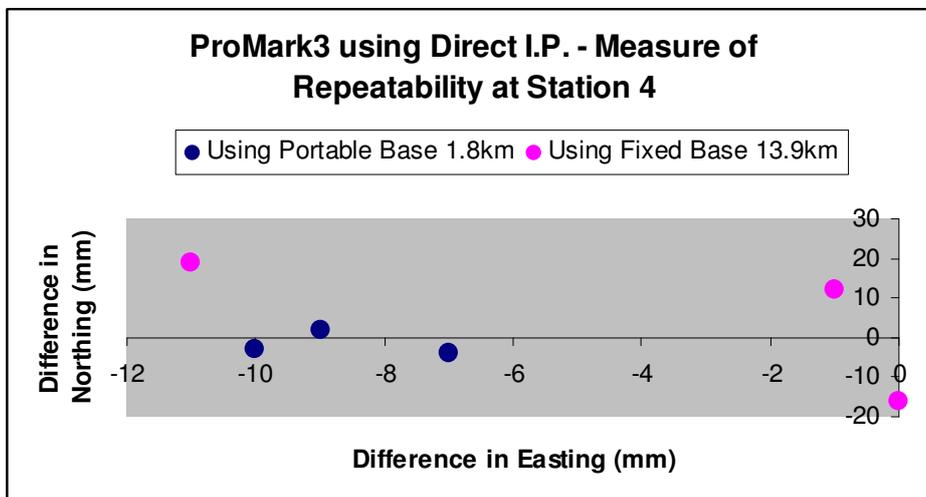
Figure 5.10 – Repeatability at Station 4

The repeatability of Station 4 is shown in Figure 5.10 above. Station 4 was measured from two bases with distances at 1.8km and 13.9km. The difference in position at 1.8km does not exceed 10mm in the east and <5mm in the north. At 13.9km positional accuracy is reasonably good in an east west direction with less than 15mm in a northerly direction.
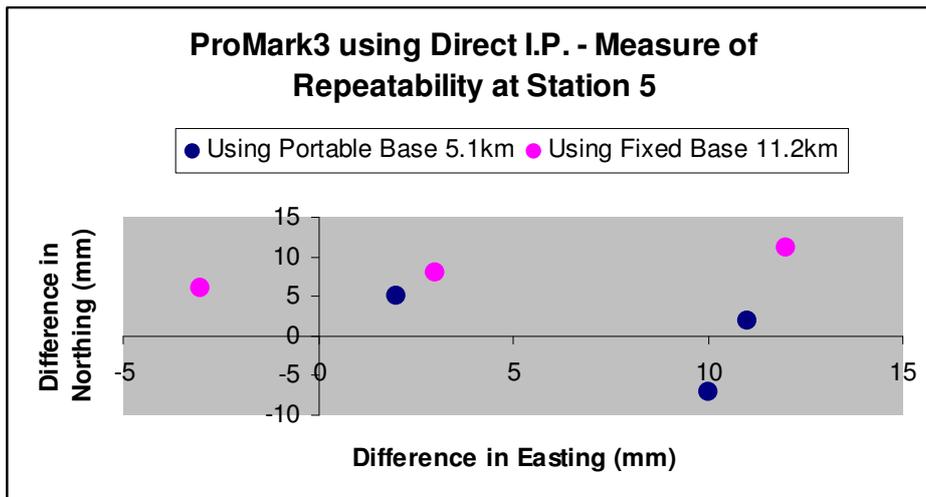
Figure 5.11 – Repeatability at Station 5

The repeatability of Station 5 is shown in Figure 5.11 above. Station 5 was measured from two bases with distances at 5.1km and 11.2km. The difference in position at 5.1km does not exceed 12mm in the east and <5mm in the north. At 13.9km positional accuracy is reasonably good in an east west direction with less than 15mm in a northerly direction.
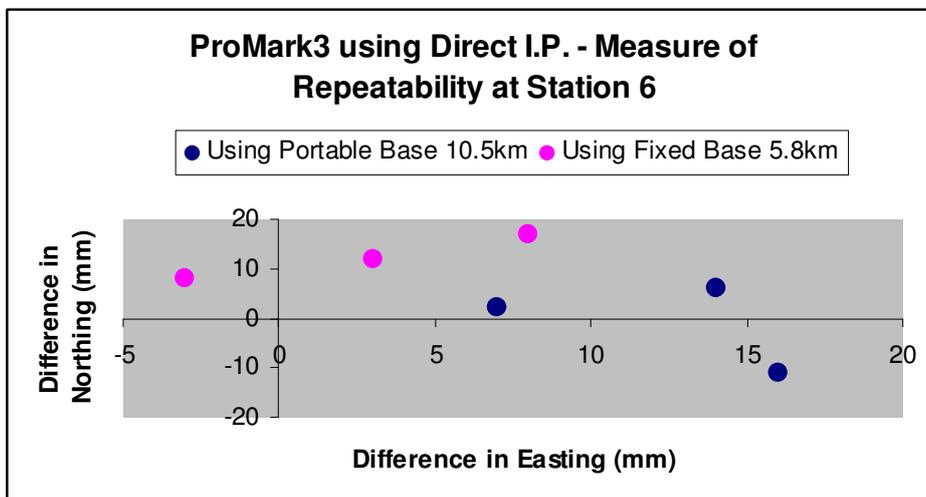
Figure 5.12 – Repeatability at Station 6

The repeatability of Station 6 is shown in Figure 5.12 above. Station 6 was measured from two bases with distances at 10.5km and 5.8km. The difference in position at 10.5km does not exceed 16mm in the east and <10mm in the north. At 5.8km the position is less than 8mm in the east and between 10 – 20mm a northerly direction.
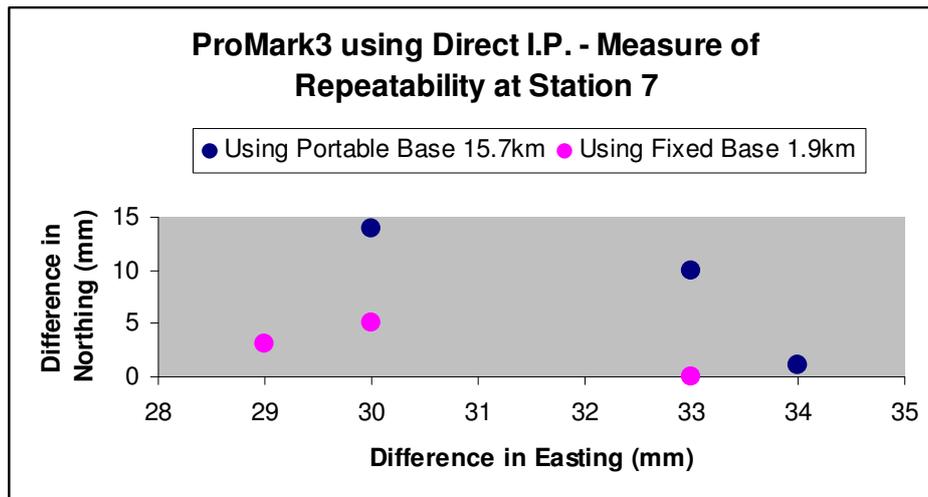
Figure 5.13 - Repeatability at Station 7

The repeatability of Station 7 is shown in Figure 5.13 above. Station 7 was measured from two bases with distances at 15.7km and 1.9km. Station 7 is a Permanent Survey Mark with known co-ordinates and with a major tree coverage to the west. At 15.7km the positional accuracy has a maximum error of 34mm to the east and 14mm to the north. At 1.9km the position is still larger in the east and less than 5mm in the north.
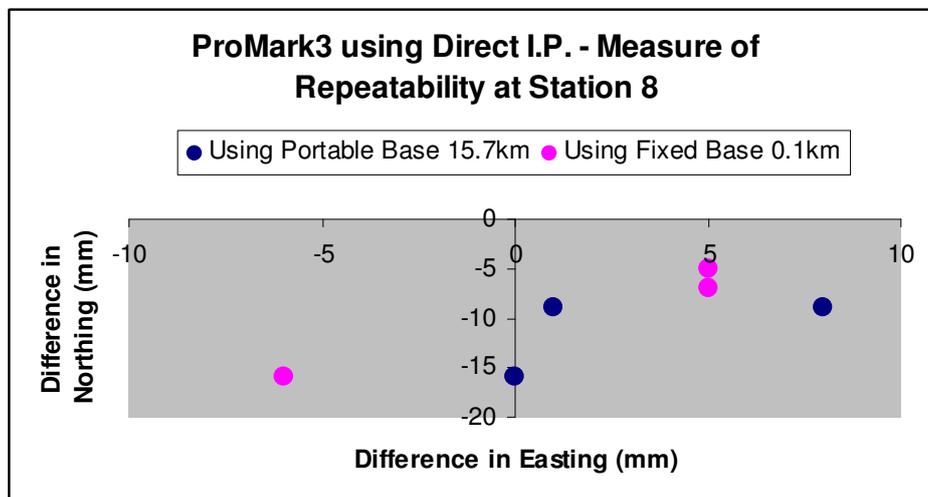
Figure 5.14 – Repeatability at Station 8

The repeatability of Station 8 is shown in Figure 5.14 above. Station 8 was measured from two bases with distances at 15.7km and 0.1km. The difference in position at 10.5km does not exceed 16mm in the east and <10mm in the north. At 5.8km the position is less than 8mm in the east and between 10 – 20mm a northerly direction
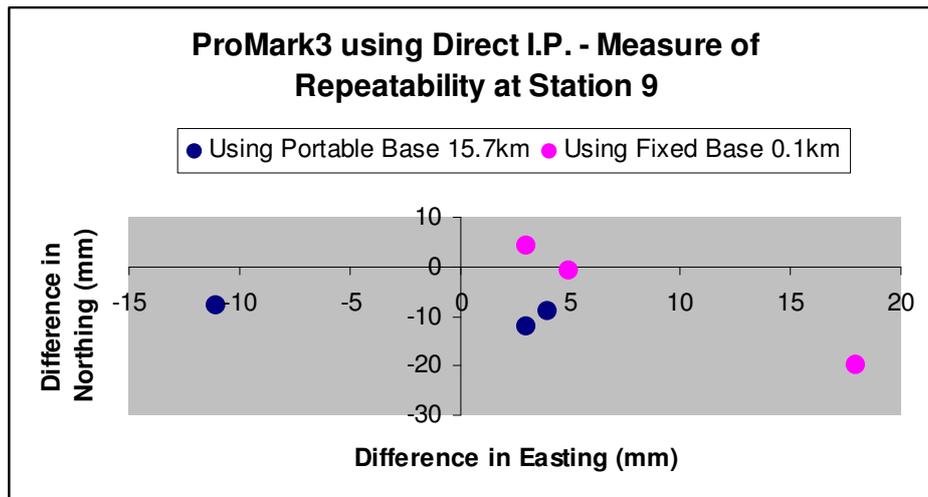
Figure 5.15 – Repeatability at Station 9

The repeatability of Station 9 is shown in Figure 5.15 above. Station 9 was measured from two bases with distances at 15.7km and 0.1km. The difference in position at 15.7km does not exceed 12mm in the east or in the north. At 0.1km the position is less than 18mm in the east and between 5 – 20mm in a northerly direction.

This concludes the repeatability testing. From the above results, it is evident that the ProMark3 using Direct IP is very accurate and will deliver good repeatability. We will now look at the height differences observed on stations 2 – 9 using Direct IP compared with adjusted heights.

5.4   Height Differences Observed at Stations 2 -9.

As well as recording the accuracy of horizontal positions, the vertical accuracy was measured using Direct IP. Measurements made are shown in Table 5.1 below. They are based on observations made using 10 satellites.

Station No.	Adjusted Ellipsoid Height	Observed Ellipsoid Height Office Base	Distance From Base	Observed Ellipsoid Height Field Base	Distance From Base
2	70.501	70.534	15.6km	70.507	0.3km
3	69.394	69.433	15.5km	69.396	0.4km
4	74.326	74.351	13.9km	74.326	1.8km
5	72.506	72.527	11.2km	72.496	5.1km
6	62.307	62.305	5.8km	62.278	10.5km
7	70.538	70.505	1.9km	70.518	15.7km
8	43.447	43.417	0.1km	43.428	15.7km
9	43.984	43.990	0.1km	43.975	15.7km

Table 5.1 – Vertical Accuracy of Stations 1 -9 using Direct IP with 10 satellites.

It is evident that the further you go away from the base, the larger the error however the error did not exceed 30mm which is very good. Locating features for a G.I.S database would be sufficient for such an error at 15km. It would also be sufficient for pre-planning surveys, paddock plans, locating permanent survey marks, bench marks or even working on an assumed datum.

5.5   Float Solution performance of Promark3.

The ProMark3 rover was setup on Station 1 and tested for Float Performance accuracy using Sydnet and NTRIP at distances of 13km, 47km, 116km and 170km.

The ProMark3 was also tested using Direct IP at 109km and without an antenna by placing the ProMark3 on the ground on top of Station 9. The results of this test are shown in Table 5.2 below.

Base Location	Rover Location	Distance	Age	No. of Satellites	Accuracy E	Accuracy N	Accuracy Ht
Mulgrave Sydnet NTRIP	Station 1	13km	2	10	0.003	0.006	0.037
Station 1 Direct IP	Station 9 (with no antenna)	15km	3	10	-0.342	-0.217	-0.132
Waterfall Sydnet NTRIP	Station 1	47km	2	10	-0.007	-0.002	-0.157
Station 1 Direct IP	Sutton Forrest	109km	2	10	0.038	-0.093	0.367
Newcastle Sydnet NTRIP	Station1	116km	2	10	0.472	0.238	-0.867
Goulburn Sydnet NTRIP	Station 7	170km	2	8	-0.460	0.085	-1.861

Table 5.2 – Float Solution performance of ProMark3 using Direct IP and NTRIP.

5.6   Latency

The latency or age of correction is time taken to receive differential corrections from the base. The ProMark3 RTK reference manual 2007, states that age should stay around 2 seconds in RTK operation.

Throughout the testing regime, the age of the correction varied between 2 – 3 seconds in both fixed and float solutions after connecting to the base station using Direct IP. The time stayed constant even in a Float solution to base stations > 100km as shown in Section 5.5.

The ProMark3 reference manual also states that if the age starts to increase this probably means that RTCM corrections are no longer being received. Several situations can occur which support this claim. Using UHF radios, the signal between the base and rover may be affected due to line of sight obstacles or other objects such as metal like reflectors. The radios also drain battery power and low battery power affects the performance of the ProMark3.

In Direct IP mode, the Latency can be affected in many ways including battery power problems, internet signals loss and poor satellite geometry. These problems are discussed in detail below.

The base station shutting down unexpectedly can cause the link to be lost with the rover. It may be that the power has been lost on the ProMark3 or the Direct IP program may have stopped running.
Using a portable field base, internet signal is very important. If the base is on the edge of the internet zone, as detailed in section 4.11, the signal will so low that it will be almost impossible to connect and achieve a fixed solution.

At the rover end, the battery power may be low on the ProMark3 or mobile telephone. This will cause the age to increase. Another problem discovered was that the Bluetooth link between the mobile and the telephone could be lost, if the mobile phone moved too far away from the rover. Although it was beneficial to have the mobile telephone separate so that it could be used for more than one purpose at the same time, you needed to ensure it remained close to rover during operation.
Other things such as operating on the edge of a mobile telephone zone with no signal on the phone caused the age to increase.

It seems that the major contributor to the latency problem using Direct IP was the battery strength. Another discovery was made proving the time taken to achieve a fixed solution was also affected by battery performance. This discovery was tested at 0.1km and at 15km and is outlined in section 5.5 below.

5.7   Battery Performance

The battery of the ProMark3 not only powers the receiver, it also powers the antenna. Without all components operating effectively, times taken to fix will suffer. On discovery that battery strength may be affecting the time, tests were conducted.

Table 5.3 below shows two tests at 0.1km and 15.5km. At 0.1km the ProMark3 connected to the base using two methods. With the battery power very low, the time taken to fix exceeded 5 minutes. The reason for stopping the test after 5 minutes was because earlier tests had proved that Direct IP at 0.1km could achieve times of 2 minutes or less. Both Direct IP and UHF radios were used and both showed similar results.

At 15.5km Direct IP was tested twice. With good battery power, the TTF was less than 4 minutes. With low power 1 test exceeded 20 minutes and was stopped. The other test recorded slightly less than 13mins, showing that the Promark3 would fix, however if batteries were fully charged, this time would be considerably less.

Communication Method	Station Distance	No of satellites	TTF (with battery power)	TTF (with little or no battery power)
UHF	0.1km	9	2mins 36 s	> 5mins (stopped)
Direct IP	0.1km	11	2min 12 s	> 5mins (stopped)
Direct IP	15.5km	11	2mins 09 s	>20mins (stopped)
Direct IP	15.5km	10	3mins 42 s	12min 50 s

Table 5.3 - Time to Fix using different battery levels on the ProMark3.

Other factors such as poor power on the mobile phone may affect the Time to Fix. This was evident on a few occasions when the ProMark3 had full battery strength and the phone was very low. For the purpose of all testing excluding testing in this section, battery strength on the ProMark3 and mobile

phone were strong. Affects from low mobile phone battery strength have not explored in this research project due to time constraints.

5.8   Internet Performance

Another question arose. Does internet strength affect time to fix a solution? Both bases used internet to broadcast the RTCM corrections to rover. The Portable Office Base used fixed line ADSL2+ where as the Portable Field Base used Wireless Internet.

This report previously outlined in Section 4.2, that with extremely low internet strength, the ProMark3 could not obtain a fix at a distance of less than 0.1km using Direct IP. Using conventional radios, almost immediately after, a fix was obtained.

Revisiting 2 stations on the baseline at 0.1km and 15.5km, internet strength was compared using wireless broadband and fixed line internet. The fixed line internet (ADSL2+) strength is 1500kbps download speed and 256kbps upload speed. The wireless broadband has a download speed of 600 – 1500kbps and upload speed of 384kbps. These figures would suggest that the wireless broadband would have a faster upload speed. It should be noted that these figures are guides only, as speed is dependent on factors such as available bandwidth, number of users and distance from tower or source of internet supply.

The results were compiled, averaged and graphed showing one result for both methods. Using only the static initialization method, the results are displayed in Table 5.4 below.

Internet Type	Station Distance	No of Satellites	TTF (Time to Fix)
ADSL2+	0.1km	9	161 secs
Wireless	0.1km	9	45 secs
ADSL2+	15.5km	10	131 secs
Wireless	15.5km	10	121 secs

Table 5.4 – Comparison of Internet strength with Time to Fix.

From this test it is evident that there is not much difference in time between using either type of internet at the base. It must be noted that the times taken to achieve a fixed solution will not only be dependent upon good reliable internet, but also base position, rover position, environment and battery strength during the survey.

5.9 Packet Data Size

Earlier in the introduction of this report, it was noted that the ProMark3 uses SBAS data to achieve faster initialization times. It was also mentioned that existing CORS such as Sydnet do not transmit SBAS data. The ProMark3 can connect successfully to Sydnet however the initialization times are considerably longer than using Direct IP. This was found in very early testing measuring to a Sydnet Station at 16km where the Time to Fix was about 30 minutes.

In the time of writing this report Sydnet has upgraded the GPS receivers on their CORS. They now output RTCM 3.0. Sydnet originally used RTCM2.3 and packet data size was larger.
The ProMark3 uses RTCM3.0. Tests have not been conducted as yet, but the ProMark3 may initialize in a faster time now that both Sydnet and ProMark3 have the same packet data size. If Sydnet was to broadcast SBAS data, then the time may be even quicker. This may be a consideration for future research.

5.10 Conclusion

This now concludes the Analysis of Results. This section has outlined the performance of the ProMark3 at varying distances along the baseline, the repeatability of position and discussed other issues such as Float Solution performance, Latency, Packet Data Size, Battery & Internet performance. An overall summary of the results will be discussed in Chapter 6 where the dissertation will conclude the projects objectives and outcomes.

CHAPTER 6 – DISCUSSION AND CONCLUSION

6.1   Introduction

Chapter 6 Discussions and Conclusions forms the last chapter in this dissertation.

The purpose of this discussion is to bring together all the research undertaken and report on the progress and objectives achieved with Direct IP and the ProMark3. The performance of the ProMark3 has now been assessed and will be documented further.

This chapter will explore the overall performance of the measurements undertaken in Chapter 4 and analyzed in Chapter 5. Other important issues such as Quality Control and Management of the Base Station, Direct IP Program - Choice and Comparison, Associated Costs – Cable, Telephone and Internet, Benefits to the Surveying Industry, Further Work needed or necessary and final conclusions will be discussed.

6.2   Discussion of Performance

With the experiments and testing complete is now evident that using Direct IP to broadcast differential corrections can improve the range performance of the ProMark3. Conventional radio is no longer needed for the user to work successfully to a range of up to 10km. Direct IP is also a cheaper alternative than radios offering speed, reliability and accuracy. There are Pros and Cons to using Direct IP and they will be briefly outlined below.

The benefits of Direct IP with the ProMark3 include,

- extending the working range up to and beyond 10km,
- offering a larger working area which improves the chance of a secure base location,
- Very quick operation once setup for the first time,
- Direct IP software is cheap and affordable. Freeware was used is this research project.

The disadvantages to a Direct IP system are,

- The rover is reliant on mobile phone coverage as well as the portable field base.
- The field base setup needs a laptop and wireless internet modem, vehicle, security and therefore expensive to guard against wet weather or if stolen.
- Distance between rover and base may be a long way. If problems occur and need attention such as software crashes or battery power, it may take time to get back to fix this.

The performance of measurement was tested with two major experiments including initialization tests (time taken to get a fixed solution) with various satellite configurations and the repeatability of position. Other tests included battery performance and internet speed. The results of these tests have been graphed and tabled in Chapter 5 however will be summarized below.

The Static and Known Point Initialization tests were conducted with 8 to 13 satellites with 10 being the mean.

Static initialisation <2km, shortest time 18 secs, longest time 2m 49s, mean time 1m 31s
Static initialisation <6km, shortest 21 secs, longest 4m 40s, mean 1m 34 secs
Static initialisation <16km, shortest 1m 13 s, longest 5m 41s, mean 3m 3s
Known point initialisation times were under 30 seconds for all distances.

Repeatability of position was also very good. All bar 1 of the fixed positions were with 25mm horizontally of the adjusted co-ordinates.

Float performance of the ProMark3 at distances up to 170km showed very impressive results. All horizontal positions were less than 0.5m, with distances up to 100km being less than 0.1m.

Vertical error did not exceed 30mm for all baseline tests. This result is very good, however checks should always be put on local control marks if available.

The battery performance showed that with low battery power, the time to fix is affected even using conventional radios. Without enough power on the ProMark3 receiver, the antenna will also suffer. At 0.1km with battery power the ProMark3 fixed in just over 2.5mins and was stopped after 5mins with no power. At 15.5km, the time to fix was also just over 2mins and stopped after 20mins with no power. No research has been undertaken in regards to mobile phone power.

Internet type and strength was also tested. Even though both bases has different types of internet there appeared to be no significant different in performance.

The overall performance of using Direct IP as an alternative to conventional radio proves to be successful and achievable. For maintaining accuracy with the recommended limits of RTK surveying, the ProMark3 and Direct IP have achieved their objectives.

6.3 Quality Control and Management of Base Station

The focus of this research project was to design a portable GNSS solution for the ProMark3 using Direct IP. Its target use would be for the individual user or small business. If that person wanted to expand its service to multiple users and allowing access to data then they would need to ensure that they implement a few procedures to maintain quality control and management.

Due to the increasing availability of RTK networks, users are becoming more reliant on these networks to provide stable and accurate data. Ensuring system availability, data accuracy and integrity would be the main issues to address.

Monitoring the positional accuracy of the base station would be one of the first issues to consider. A reference station erected in a permanent position would be surprisingly dynamic over time due to sources of localized movement including accidents, weather, vandalism, or even widespread movement such as tectonic movement (i.e. earthquakes). Tectonic movement doesn't have much effect in Australia due to our great distance from fault lines however, regular monitoring would be important to ensure system accuracy.

Other movement could be in the form of chronic movement which is caused by mining activities, drilling or aquifer flows. It is therefore imperative that regular monitoring of the station be addressed. This could be achieved by applying long term post processing techniques or regular static surveys.

Monitoring software would also be useful. This type of software can sound alarms when movement rates exceed the preset co-ordinates of the station.

From the user end, it is important to ensure precision repeatability. It is crucial to make sure that the geodetic reference frames between the base station and local control marks are consistent. RTK solution and techniques provide a double differencing, fixed ambiguity solution. The advantage of this solution is that it is quick and accurate. However the disadvantage is that solutions are highly dependent on satellite geometry and are still susceptible to multipath at the rover. It would be advisable that the user undertake site calibrations and undertakes checks to local control especially for vertical measurements.

The portable base station would still follow similar guidelines to retain accuracy and reliability. Setting the base on a known survey mark would ensure that your measurements are accurate relative to that known point.

Other things such as the type of data transmitted will determine the user. The ProMark3 transmits RTCM3.0 where as other GNSS users can only receive RTCM2.3. The ProMark3 also transmits SBAS data which would be useful for other ProMark3 users but of no use to other receivers. The ProMark3 has found this problem when accessing local CORS. Some CORS are now transmitting RTCM3.0 and also SBAS data. These issues would have to be addressed if planning to share base station data.

Providing access to the system is another issue. There are community networks that provide free access and other commercial enterprises that charge a fee. Some providers also store base station data where as others just provide real time access. Passwords, IP address and Port Number will need to be provided. Private operators will not have to worry about this if they only plan to use for themselves.

Knowing how many users can access the base station at the same time will depend on the type of software used. Some software such as Utilserver, can allow 50 users at once to access the base. The user also has the option of informing users that the IP address of the base station has changed. Users can be informed via email of the changes. GPSD which was used for the entire research project does not have this capability. Testing also suggested that about 35 users could access the base station using GPSD however no documentation has been made available to support my claim.

The operator of a base station broadcasting corrections over the internet needs to ensure that the system is working in the most effective way. Regular monitoring of the stations position, updated information of position and equipment calibration or servicing would be essential. If the operator plans to service more than 1 client other information such as operational times, the co-ordinate system the base station is working on, scheduled outages and upgrades will all be important factors in maintaining reliability and service.

The user needs to make sufficient checks on their work and not solely rely on the data received. Simple checks could be made by site calibrations, or measuring local control and reporting discrepancies to the operator if they find errors that they believe are genuine.

6.4   Direct IP Program - Choice and Comparison

GPSD is freeware program and its source code is the public domain. It was chosen primarily on cost for this is a research project. Other Direct IP programs such as Utilserver, TCP COM, GNSS Surfer and many more have demonstration versions which can also be used. In demonstration mode, the program can sometimes be limited to 1hours use at a time or features could be disabled. To purchase the programs can also cost several hundred dollars. GPSD was not time limited and suited the project perfectly. I could operate the program with ease and without worry and for free.

GPSD is a daemon (program that runs in the background) that will monitor a serial port for messages sent by a GPS device and broadcast it on a TCP port. It actually broadcasts anything that comes in on the serial port, so you could use GPSD to do an internet broadcast of any device (i.e. GPS, an atomic clock, an acquisition device etc.)

GPSD software is very small in size being only 1.7Mb compared to Utilserver being greater than 25Mb.
It monitors the serial port for messages sent by a GPS device and broadcasts them on a TCP port.
It is a command line executable program as shown in Figure 6.1 below and is very easy to use.
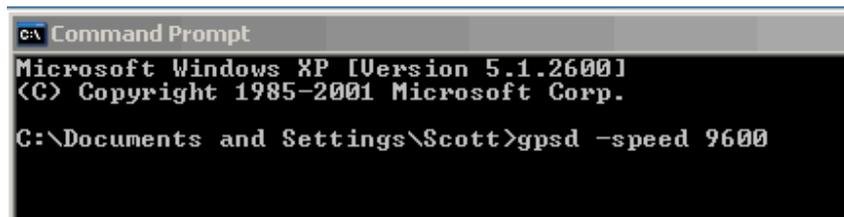
Figure 6.1 – GPSD command line executable program.

GPSD stopped working only when the internet connection was lost. It happened using the wireless internet where internet signal is less reliable. Using fixed line internet the program ran successfully running for 3 days straight without any problems. Without understanding the programs capabilities or without implementing a quick start up method, you will find it very hard to know if it's working properly. That would be biggest problem faced with the program. To overcome that, I created an internet link to the IP address and Port Number of the base station. Upon execution, a series of alpha numeric and numbers appeared on the screen. This was an indication that the computer was receiving GPS data.

As explained in the previous section, I tried testing the number of users that access the base operating GPSD. I managed to get 35 separate connections at the same time. This process was tested using the internet address of the base from separate computers. Coordinating 35 people with a GPS for the project was difficult. I could not get any documentation from the creator of this program and therefore I cannot support my claim any further.

GPSD is a simple, easy to use program and worked very well for the project.

Utilserver software is intended for the retransmission of GPS corrections over the internet. It was written for MICROSOFT.NET framework 2.0. Utilserver can host up to 50 users and offers additional features such as NTRIP and Mirror Mode functions. These will not be explained in detail as they have been covered in the Literature Review in Chapter 2.

The program can offer clients a service to inform them via email, when the system has gone down or when changes are made in regards to IP Address and Port Number settings. Other features include an onboard clock monitoring the length of time the program has been operating for, input for two serial ports to host more than one GPS at a time and a screen which displays the data coming through from the GPS to show you that it is working properly. The Utilserver operating screen can be seen in Figure 6.2 below.
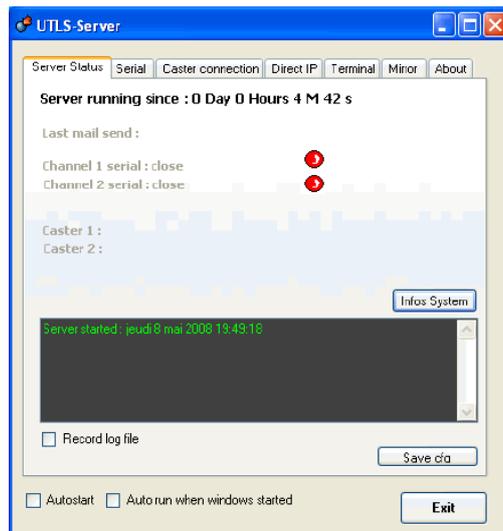
Figure 6.2 – The Utilserver Operating screen.

This program is not freeware and must be purchased to use its full applications. It does offer a demonstration version which gives 1 hours access. It also comes with an instruction manual and support from the developer. This was an added benefit over GPSD.

Direct IP programs vary in price and features however are reasonably easy to operate. It will depend on the need of the operator and budget. They do not take up much space within your computer either.

6.5 Associated Costs – Setup, Telephone and Internet

Costs for setting up the base station include the purchase of an extension antenna coaxial cable. Prices have been quoted from an American manufacturer and may vary from different manufacturers worldwide, but to give a general idea prices start at $25 USD per 30m for the RG58. An alternative to the RG58 is the RG142 cable which costs $165 USD per 30m. Coaxial cables also have different strengths, thicknesses and efficiencies. All cables have TNC connectors to attach to the ProMark3 and antenna. The purchase of a splitter box costs approximately $300 AUD. Any additional cost for erecting the base on a roof cannot be accounted for as that would depend on conditions and design.

Magellan recently released a paper in October 2008, titled GNSS Equipment Interoperability which said that cellular plans usually base the monthly charges on the amount of data which is exchanged.

Although RTCM 2.x represents the most interoperable message format, it is also the most costly format to utilize with cellular service. Depending upon the amount of time spent receiving corrections and the correction format being used, the following data usage estimates can be made (GNSS Equipment Interoperability, 2008) as shown in Figure 6.3 below.

	Data usage per hour with 8 satellites (Typical GPS constellation)	Data usage per hour with 12 satellites (Typical GPS + GLONASS constellation)
DBEN	0.779 MB	1.207 MB
RTCM 2.x	1.169 MB	2.011 MB
RTCM 3.x	0.531 MB	0.822 MB
CMR	0.535 MB	0.829 MB

Figure 6.3 -   Data usage for GPS and GLONASS constellation with various data configurations. (GNSS Equipment Interoperability, 2008)

ProMark3 GPS receivers, talk to each other in correction format RTCM 3.0. This means that it is about 0.53MB / hour for 8 satellites. Internet service providers offer various plans to access internet.

At the office base end, the Telstra Bigpond ADSL2+ plan was $69.95 per month. This allowed 12GB of upload and download data. By referring to figures in the table above, a base station running for 24 hours would only use approximately 12MB of data. Running the GPS for 30 days would only accumulate 360MB of data still leaving 11.64GB remaining. Therefore usage is very affordable.

For the field base, 3 Mobile Broadband basic plan charges only $29 / month giving you 2GB of data with additional usage of 10c per MB. Working out the 3 Mobile Zone, is charged at $1.65 / MB.

At the rover end, Telstra's 3G Wireless Broadband basic plan of $5 per month gives you 5MB of data with $1 per MB after that. This would work out to be $1 per 2 hours of work. As you can cover a large open area in 2 hours, the cost is very minimal.

In summary the costs for setting up such a system would be very small. If you were to use the system for 4 working weeks at 8 hours per day, you would be looking at a cost of $80 at rover end and approximately $70 at the base end costing $150. This on top of the initial setup costs, is very affordable for a surveying firm and a small charge to be offset against the client.

6.6 Benefits to the Surveying Industry

With expanding CORS networks and implementation of VRS, surveying firms are able to minimize costs by not having to invest large capital by purchasing Base and Rover GNSS Systems. A RTK system is made up of 2 GPS receivers. A surveying firm using CORS could theoretically employ two separate field parties if desired.

Existing CORS such as Sydnet have been slowly increasing the amount of reference stations throughout N.S.W and as the popularity for this method of surveying increases, local governments and private organizations may follow the same path by implementing their own systems.

Currently the existing CORS are spaced greater than 10km apart even in the metropolitan areas. This does make it difficult for users of single frequency RTK as recommended working distances are limited to 10km. The existing reference stations do not have sufficient overlap which creates gaps and large areas whereby access to the reference station data is impossible.

The benefit of establishing a portable base would allow users to work in areas not serviced by existing stations. This would be especially useful in country areas. Access to mobile technology in county areas is no longer a problem as larger telephone companies increase their service capability by building more infrastructure such as towers and underground services due to increase need of residents especially created by new subdivisions.

This research project has looked at ways to create a privately run reference station either from the office or the field. These systems would benefit surveyors working in open cut mines, construction sites and in large open spaces for detail or cadastral purposes. The system would also prove useful in agricultural industries such as farming and crop management and by providing greater access to spatial data.

6.7   Further Work

This research project has addressed the major issue of the range problems associated with the ProMark3. The following paragraphs outline future work which could expand upon the issues addressed in this dissertation.

The battery power was tested on the ProMark3 however the mobile phone power was not tested. Times to fix a solution may be affected by poor mobile phone power which also affects internet connectivity.

Coaxial cables are another issue which needs further investigation. At the completion of this research project Direct IP usage has increased in popularity amongst other users of the ProMark3.
Through various internet messages boards such as the Point of Beginning website for Magellan / Thales, http://www.i-boards.com/bnp/pobtha/ a ProMark3 user claimed to have used a 30m long RG58 coaxial cable to create a Direct IP reference station. This contradicts my research as I could not achieve this and so further investigation would be needed to resolve this issue.

Simplicity of the field reference station could be investigated. Reducing the size of the station, minimizing the computer needed to power the Direct IP program and looking at ways to prolong power could be addressed.

Finally, testing was undertaken with good open sky conditions. Different variations of terrain, satellite geometry and distances from mobile telephone towers could be also tested and reported upon.

6.8   Conclusion

The aim of this research project was to investigate the use of Direct IP with the ProMark3. The ProMark3 does have a limited working range using conventional UHF radios but with the use of Direct IP this problem has been overcome. The achievable working distance was tested up to 17km successfully which exceeds the recommended limit of 10km for single frequency RTK.

The designs for the portable GNSS system show a simple yet effective solution for creating a private reference station. As explained in section 6.5, alternatives or other ways to erect the base could be explored in future research. The design has met the requirements set out in the objectives of this project.

The experiments conducted found that the ProMark3 performed very well for a single frequency receiver. Times to fix a solution were very quick up to 10km and the repeatability of position showed that the accuracy was sufficient for real time positioning.

Other factors such as cost, reliability and benefits to the surveying industry have been addressed as well as discussions on various Direct IP programs, Internet speeds and issues affecting the system such as battery power.

This research document has addressed all the relevant issues regarding Direct IP and the ProMark3. Until the day comes when every major town has access to a CORS, users will be limited only to certain areas to access reference station data. The development of portable base station would extend the working range of the ProMark3 and bring the data to areas not currently serviced by CORS. Surveyors, engineers, private organizations and governmental departments would all benefit from this technology. For the simplicity of use and affordability, Direct IP with the ProMark3 would offer a fantastic solution to single frequency RTK operation and performance.

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APPENDIX A – PROJECT SPECIFICATION

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR: Scott Daniel Taylor - 0019922860

TOPIC: Development and testing of a portable network GNSS solution using the Magellan Promark 3.

SUPERVISOR: Associate Professor Kevin McDougall.

SPONSORSHIP: Mapsoft – Mr.Ian Iredale.

PROJECT AIM: The aim of this project is to investigate the development of a portable network GNSS solution using the Magellan Promark 3 and Direct I.P. and to undertake a range of tests to determine its accuracy and latency limitations.

PROGRAM: (Issue D 17[h] March)

1. Conduct a review of literature into the use of Virtual Reference Systems and CORS network initiatives with particular reference to the use of internet protocols.
2. Establish a basic home/office and portable network GNSS data stream via the Internet, using a Magellan Promark 3 base.
3. Establish a robust testing regime for accuracy, reliability, range, repeatability, efficiency, capacity, cost and latency of the Promark3 receiver using Direct I.P. including its application to conventional survey operations.
4. Evaluate different freeware and shareware programs in terms of their operation and capabilities.
5. Analyse and discuss the results of the field experiments and discuss the application of the technology to the survey industry, particularly issues of reliability, cost and quality control.
6. Document the project in the form of a project dissertation and present a professional powerpoint presentation.

As time permits:

7. Extend the testing of the system with other conventional RTK or CORS/VRS solutions.

AGREED _____ (Student) _____ (Supervisor)
Date: 17 / 3 / 2008   Date: 31 / 3 / 2008

Examiner/Co-examiner: _____ .