The Long Road to Establishing a National Network RTK Solution

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ABSTRACT

The ability to receive a Real-Time Kinematic (RTK) GPS correction from any national location without the need for a user to establish their own base station, is a utopian concept to land surveyors. The idea is beginning to become reality however with many government and commercially led networks being established and tested throughout the world.

Ordnance Survey (Great Britain's National Mapping Agency) has over 350 surveyors deployed throughout GB collecting survey data on a daily basis. This data is used for the revision of the National Topographic Database (NTD) – the large scale digital map of Great Britain. Ordnance Survey seeks to maintain the currency of the NTD to an increasing standard and looks to RTK GPS to help achieve this important goal.

This paper describes a prototype project undertaken by the Ordnance Survey. The project installed and ran a network of 20 GPS reference stations in northern England and looked to investigate just as much the software, communication and data fusion issues as answer questions on potential accuracy and station spacing. The configuration of the network components is presented, the 'lessons learnt' so far within the project and the viability of a National Service is discussed. The testing strategy is described along with expected accuracy and performance. In particular the paper discusses the problems that need to be solved in setting up a national (rather than local) RTK service.

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1. INTRODUCTION

The Ordnance Survey is a UK government agency which is tasked with mapping the entire country at scales between 1:1250 and 1:10000. The Data Collection and Management (DCM) section within the Ordnance Survey employs approximately 385 field surveyors to maintain and enhance the National Topographic Database. DCM continually strives to improve the efficiencies of its data capture processes. GPS has become the survey tool of choice not only within DCM but also in the wider positioning community. It can be safely anticipated, and is widely accepted, that GPS will be the most efficient survey tool both now and for the foreseeable future, achieving greater flexibility and productivity at the detail survey level. It follows that for DCM to improve its survey efficiency it must look (mainly) to improvements in the use of GPS.

RTK provides the surveyor with a real time position at the few centimetre level. This is achieved using a single, survey grade, dual frequency GPS receiver. RTK is usable without a National network but this requires the use of a local base station. Such a local solution requires the surveyor to set up the local base as well as determine its precise position. A national, broadcasting, RTK solution would give an instantaneous high quality answer to DCM surveyors anywhere that the signal is available (anticipated to be all major urban areas). A network solution also aims to give greater accuracy, reduce bias sources and to produce a more robust solution to the surveyor. The internal project described within this paper aimed at determining the technology configuration as well as the efficiencies and accuracies possible through a national RTK network in GB. Ordnance Survey require (for internal Data Collection activities) a horizontal precision of 5cm to 12cm (five to twelve centimetres) at one-sigma for its GPS coordinated points (at 1:1250 scale).

2. DESCRIPTION OF THE STUDY

The DCM initialised an internal project in the summer of 2001 to investigate and establish a network RTK solution in northern Britain. The project was carried out along with the Ordnance Survey’s GPS partner, Leica Geosystems, and the German company Geo++.

The key objectives of the project were to:

- Set up a usable Prototype RTK Network sufficient to test the system;
- Prepare a Business Case for a National RTK Network if the project was successful;
- Determine the achievable performance parameters;
- Determine the efficiency gains that can be made and assertain the level of risk involved.

3. NETWORK CONFIGURATION

For conceptual ease, an RTK Network can be described as consisting of three basic segments (rather like GPS itself). These are the data; collection, manipulation and broadcast elements. The relationship of these components is shown in figure 1.

3.1 The Data Collection Segment

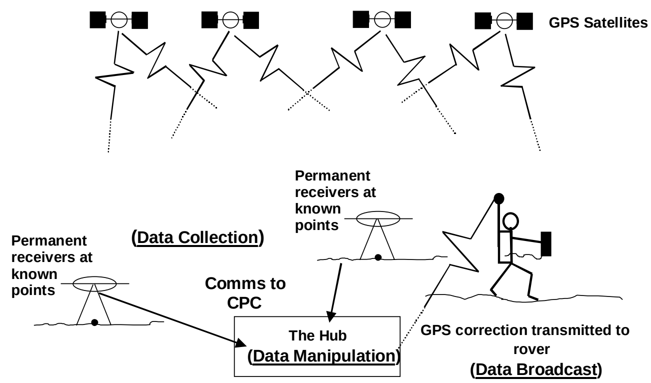


Figure 1. Concept of the network approach to RTK correction delivery.

The base stations consist of Leica RS500 dual frequency GPS receivers. The receivers require only small memory capacity as the data is passed, in real time, direct to the Hub for data manipulation. The site must be secure and suitable for good GPS observations (clear horizon etc). The acquisition of base station sites is undoubtedly a critical part of the network build. Ordnance Survey choose to site stations on buildings as this provides easier access to communications and power as well as security. Other networks have chosen to establish GPS installations on custom monuments. Ordnance Survey will investigate this approach before committing to a national deployment.

Obtaining sites for the base stations has been, by far, the most time consuming part of the Project to date. An added complication is that this stage relies heavily on the input from 3rd parties, most of whom have little interest in the Project. This makes planning a very difficult, imprecise and unreliable process. Ordnance Survey were fortunate in being able to establish 5 sites quickly which enabled some development work to start on the Hub whilst the remaining sites were procured and set up. The choice of sites available falls into four broad categories;

Existing Active Network GPS sites: Ordnance Survey has previously deployed a total of 30 Active GPS base stations (www.gps.gov.uk), of which eight were available to the Project. These stations to aid the definition of the reference frame in Great Britain and our used both internally and externally to locate local survey base stations. Converting these stations to RTK status was an easy and quick process.

Partner Sites: Ordnance Survey is conducting the Project in partnership with two major customers, the aim being to assess the effect of a National RTK Network on such customers. As part of this partnership, sites owned by the customers have been made available to Ordnance Survey.

Ordnance Survey Offices: A total of 5 Ordnance Survey field offices exist within the area of the Prototype Network. The owners of these buildings were approached to obtain permission for the establishment of a base station. Generally this was a slow process (average elapsed time of about 4 weeks to obtain permission) and in one case, Manchester, an agreement was not possible. At this site the owner insisted that Ordnance Survey would need to make a payment for the site. This raises the serious issue of whether payment should be made for base stations and communications installations, something that is waiting agreement internally.

3rd Party Sites: These were even more difficult to obtain. Experience showed that the first question asked was “how much are you willing to pay?” Sites were restricted to public service occupiers such as Police, Emergency Services and Government Buildings. Even so, the process of obtaining permission was protracted and littered with legal implications.

3.2 The Data Manipulation Segment

The specification for the data manipulation / processing computer engine (the Hub) are detailed in section 3.2.2. With a view to maximum reliability, all components of the Hub are duplicated, this not only includes the computers but also the power supply and hard disks. The hub is based in Ordnance Survey headquarters at Southampton with and contains 6 Dell PowerEdge 2550 servers with a specification of;

- Intel Pentium III 1GHz with 256K on board cache (provision for 2nd processor)
- 1 Gb of core memory (RAM). Expandable to 4Gb.
- 2 Ultra 160 SCSI 18Gb hard drives, controlled by RAID 1 configuration
- Hard drives and power supplies are capable of hot swapping.
- 48x IDE CD ROM drive
- DRAC II server management card with LAN connection and modem.

The computers are all controlled from a single keyboard and display built into the rack. 30 ISDN lines supply the Hub. These bring data from the remote base stations (see figure 7) in real time.

The Hub consists of three components; front end, main and dial-up processors, with each component requiring one server. However a second computer mirrors, in real time, its companion. In the event of a malfunction the back up computer takes over the task of the primary computer. This allows the malfunction to be rectified without the Hub being taken out of service. The Hub is running under Windows 2000.

Geo++ provides the software running on the Hub (section 3.2.2). To avoid wasteful travelling this configuration is achieved remotely by Geo++ personnel located in Germany. At the time of writing this is done with a ‘simple’ dial up line but there are plans to make the Hub available on the web. This will allow multiple developer access, with appropriate security restrictions in force.

3.3 The Data Broadcast Segment

In a National RTK Network, the RTK signal is not delivered by the base station but by The Hub. For the purposes of the current Project, Ordnance Survey intend to trial two modes of broadcast; VHF and GSM (soon to be GPRS). At the time of writing (January 2002) Ordnance Survey have not yet delivered this phase of the Project. SmartGate receivers, Geo++ [2001] are to be used to receive the corrections during testing as they are able to interpret the additional information within the FKP parameters, see section 3.2.2. Provisionally, it is thought that about 20% of the total usage of the network will be carried out via GSM. The remaining 80% will be achieved via VHF.

3.3.1 VHF

In a developed country like Great Britain, the radio spectrum is extremely crowded. To avoid development costs for the radios Ordnance Survey would have preferred to use the same hardware as used by the German SAPOS™ network (www.sapos.com). Prior to Project start, Ordnance Survey visited SAPOS™ where a 2m-band VHF delivery system is being used with excellent results. Unfortunately, on return to GB, it was discovered that the frequency used in Germany was not available within GB. This illustrates the importance of ensuring that suitable frequencies are secured very early in the development of a National RTK Network. To achieve VHF delivery, Ordnance Survey is now required to develop a 4m-band radio, this has added to the cost and delay. It is strongly recommended that any plans to build a National RTK Network should include allocation of suitable broadcast frequencies as an early deliverable.

The second difficult aspect is the acquisition of suitable broadcast sites. The modern move to high bandwidth wireless communications means that it is fast becoming common knowledge that good broadcast sites are worth considerable sums of money. An added factor is that many of the suitable sites are either already fully occupied or the owner has signed an exclusive deal making that site un-available.

3.3.2 GSM

Given a developed mobile phone network, the most straightforward delivery mechanism is GSM – the low risk approach. The Hub has provision for dial up and the corrections are delivered direct from the Hub to the user via the GSM network. The major drawback is cost as the user needs to be ‘logged on’ constantly while using the correction service, at a call charge of ~£0.12 per minute. This can be mitigated to some extent by adopting suitable working practices in the use of RTK. This cost will be significantly reduced with GPRS as the user only pays for the data packets received, not the entire call duration. Within the current Prototype Network, provision for 8 GSM lines into the dial-up computer have been made. This can easily be expanded as the system moves from development to production.

There are however other possibilities to send corrections to the users, these are;

- Private radio system. This will require 7 frequencies transmitting from 25 base stations. Ordnance Survey has no experience of this type of activity, and carries high fixed costs. However, it is easy to use, and would provide national cover.
- Satellite connection via the Iridium service. The Iridium service price structure has reduced dramatically, however, it is still too costly due to ‘long call’ type of operation.
- Broadcast of the correction via FM modulation on an existing bearer, or via Digital Audio

Broadcast (DAB). The BBC have been approached regarding this option.

3.4 Configuration

3.4.1 Field Network

The Prototype Network has 20 stations, figure 2. The design spacing of these stations is on average 60-70km, with the longest baseline being 84.5km and the shortest of 39.2km.

Figure 2. The positions and extent of the test Prototype network

As mentioned in section 3.1.1, Ordnance Survey is undertaking this Project in partnership with two major customers, one being Yorkshire Water, part of the Kelda Group plc, who provide water and sewage services to 4.5 million people. The network was designed to cover their area of interest.

Figure 3. Antenna installation at a remote station.

All base stations are situated on existing buildings, figure 3 shows an example installation. Generally the antenna is mounted on a stainless steel pole which is secured to the building, with the GPS receiver and ancillary equipment housed in a solid, purpose built cabinet, figure 4.

The Project was again dependant on 3rd party suppliers for the installation of ISDN lines and power. It is clearly desirable to include the provision of these services at an early stage in the Project.

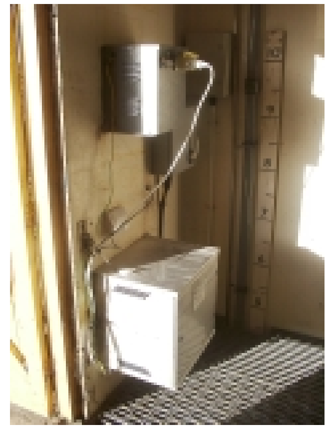


Figure 4. Receiver, power and communications housed within secure boxes.

All equipment is clearly marked and contact telephone numbers inscribed on all installations. This has proved very useful in allowing contractors to contact the right people quickly - it is easy to become complacent with the sophisticated and complicated equipment.

3.4.2 Concepts of Hub System and Software

The Hub System located at the Ordnance Survey Headquarters in Southampton forms the computational backbone of the test setup for the RTK-networking solution. All GPS observation data from the Project network are collated at this facility. The computational capacity available during the test setup phase consists of several computers running under Windows NT™, figure 5, described in section 3.1.2.

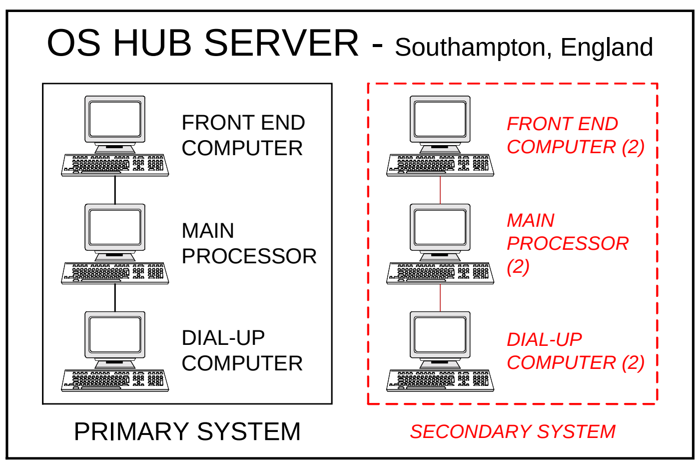


Figure 5. Components within the data processing chain and hardware redundancy at the Ordnance Survey Hub server

The data-processing chain begins with a computer that controls all the reference stations directly via ISDN communication lines. It should be noted that those continuous reference stations forming part of the Active network cannot be independently controlled from the hub facility because of their high priority assignment within the Active station network. The operational functionality of this well-established service has to be maintained during the RTK networking test to serve its existing users. The in-coming GPS observation data from all operating Ordnance Survey reference stations is screened for blunders and reformatted according to the internal data interface within the communication computer.

Deviations due to different antenna models are corrected with the application of absolute antenna phase center variation parameters (PCV) as being discussed in great depth in the scientific literature (e.g. in Wübbena et al [1996], Wübbena and Willgalis [2001]). Furthermore, the available information in its original uncorrected state, is converted to the RINEX standard and archived for post-processing use. Their archived data can then be transferred to an additional server for data distribution via the Internet.

The next link in the data-processing chain is the networking computer which retrieves the data from internal memory to use in processing a networking solution. The Geo++ program module GNNET carries out this task while the coordinates of the continuous and permanent reference stations are held fixed. The purpose of a networking solution is the mitigation of baseline length dependent dispersive and non-dispersive error influences. The active ionosphere effects the dispersive influences whilst variations within the local troposphere and deviations of the broadcast orbit from the true satellite orbit effect the non-dispersive influences. All of these influences are modelled and estimated in different modules within the GNNET software, described fully within Wübbena et al [2001].

The last link in the chain is the information distribution computer which accesses the estimated information as supplied by GNNET and reformats it into a distribution format based on the international RTCM standard. The primary means of distribution investigated are the GSM and 4m band VHF. The current GSM data distribution approach permits transfer of information in both directions between user and computation centre, and therefore allows manipulation of the transmitted data to a location near to the user requesting the information. The whole software setup could then provide the information in a so-called virtual reference station mode. However two major reasons prevent the realisation of this approach. The first is that the intention to provide the network information via a radio transmitter and that the information distribution concept should not be dependent on the facilities used. The second major reason is the non-conformity to RTCM standards of the virtual base station approach. Of course, successful development tests have been carried out with such a mode, however the complete operation is not described and agreed upon by those manufacturers supplying GPS rover equipment specifically for high precision position collection. The designed RTK network has to also provide the necessary information for other manufacturers' GPS equipment. Therefore the information distribution process is defined using the RTCM-Standard and the so-called FKP coefficient representation of the modelled biases. The abbreviation FKP stands, in German, for Area Correction Parameter and its use allows for mitigation of the error influences at roving units in the field.

The advantage of this distribution approach is the open availability of permanent reference station information in a standardized format of RTCM message types 20 and 21 to that field equipment not having access to the additional FKP information provided by the combined network. At least this equipment could, dependent on the actual manufacturer's specifications, operate within a certain distance around the reference station, using type 20 and 21 messages as the primary information source. In the future, it is planned to use a new RTCM message type, currently under discussion, which will also use the information of surrounding stations in a standardized way – if it is accepted. For additional information on this proposed RTCM standard, the interested reader is referred to Euler et al. [2001] and

Zebhauser et al. [2002]. The goal for the permanent network is to use an information message standard that is supported by the high precision positioning equipment of all major manufacturers.

The computational equipment at the hub contains redundancy for each link within the data-processing chain. This affords two independent chains capable of running operability checks and initiating automated resets of the opposite processing chain, if ever required. In general, one system will be designated as the primary system to provide the information for all field operations. In case of operational difficulties within the primary chain on the hub (for example hardware problems), this system can switch automatically to the secondary (redundant) system. This ensures very high reliability of the whole RTK network system at the processing center however this cannot mitigate failures at individual permanent reference stations. Although in case of failure at any station due to power outage or other unforeseen difficulties, the whole network setup should be sufficiently robust to support field operations with minimum degradation.

The second operation chain will issue, if required, messages for operator assistance and/or it will duly start an automated procedure to bring the failed data-processing chain back to a proper operational status. After a recovery, the whole system would then again soon possess redundancy. Operational experiences with other networks have shown that such redundancy is beneficial in ensuring that the overall availability and integrity of the whole system remains at the highest possible level. This redundancy, is required as noted already, in case of an unexpected hardware failure, but should not be required very often. The additional hardware redundancy becomes advantageous also for maintenance when, e.g. components have to be upgraded and so on. Additionally for post-processing solutions, the original observations are archived in RINEX and therefore data loss during critical and expensive operations, such as aerial photogrammetry flights, is minimized. However failures in the communication chain between the permanent reference stations and the hub, or failures of individual stations, cannot be mitigated with such approaches. Only a complete albeit very expensive, redundant second operational system with duplicated components can provide the ultimate safety and reliability for the operation of a permanent RTK system. For normal surveying type applications, the existing redundancy is sufficient to prevent field crews being without an operational data link to a reference station that is capable of providing the network information critical for precise RTK-GPS positioning.

3.5 Communications and Infrastructure

3.5.1. Background – The Existing Ordnance Survey Wide Area Network (WAN)

The existing Ordnance Survey WAN is a result of the evolutionary development of Ordnance Survey field systems. The 68 Ordnance Survey field offices are connected to OSHQ via ISDN2 dial-up connections. Ordnance Survey is linked to it's Internet Service Provider (ISP) via a single 4mg leased line connection, and remote dial-up connectivity is provided by two Shiva Remote Access servers giving 40 lines at 36kps and a single Cisco 3640 providing connectivity for thirty (30) users at 56kps.

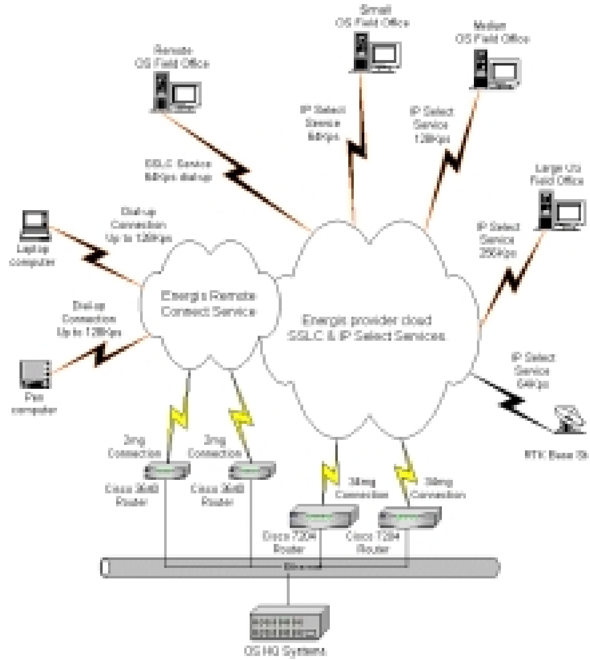


Figure 6.The new Ordnance Survey WAN

In April 2001 a project was initiated within the Ordnance Survey to upgrade the WAN. This was undertaken as a response to a number of business drivers; increased demand, need for flexibility, reducing cost, external restructuring and a requirement for a mobile solution - future field based systems requiring a mobile option.

The new service to be implemented by Energis is a fully diverse system providing full redundancy in operation. The primary interface consists of twin 34mg connections between the two OSHQ computer suites and the Energis provider cloud, figure 6. Field offices are connected to the provider cloud by a number of options tailored to the local requirement. RTK base stations are to be connected to this provider cloud via the IP Select 64kps fixed line service.

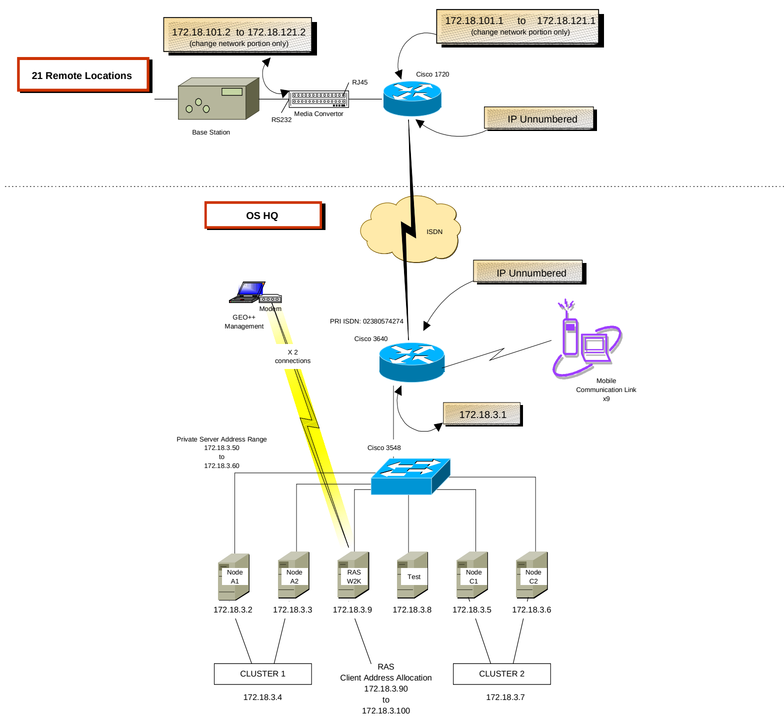
Dial-up connectivity is to be provided by the Energis Remote Connect service. This will allow connection by almost any dial-up bearer type, for example PSTN, GSM, GPRS, DSL and ADSL. There is capacity for up to 1000 simultaneous users. The connection to the Ordnance Survey LAN for this service is via a pair of 2mb lines, again providing redundancy in the infrastructure design.

3.5.2 The RTK Prototype Project Communications Requirement

The high-level communications requirement for the RTK Prototype Project was relatively simple. Twenty base stations were to be connected to the Hub server in OSHQ on a 24 x 7 basis, with the facility to allow RTK data users dial-up access to the derived corrections. In practice, various issues complicated provision of such a network:

- The ongoing WAN upgrade project.
- The complexity and additional security issues associated with multiple direct dial-up connection, especially the need for external access by third parties. It was deemed unsafe to host the hub servers in the Ordnance Survey computer suites.

Figure 7. RTK Prototype Diagram



The agreed solution was to create a separate WAN specifically for the RTK Prototype project using ISDN dial-up services to connect to the base stations, figure 7. ISDN was chosen over PSTN due to its reliability, existing experience in using ISDN solutions, and the lower call costs that could be negotiated for the ISDN connections. The RTK WAN will be migrated to mainstream Ordnance Survey systems following the successful introduction of the Energis services.

Several major communication issues have threatened the creation of the network in the agreed timescale;

- The Leica receivers output the data string via an RS232 asynchronous connection. To connect to the Cisco 1720 routers, an interface to a standard RJ45 connection was required. The current workaround is an interface device that takes the asynchronous data string, and encapsulates it in an IP packet for transmission. The Geo++ software loaded on the hub removes the IP shell. Unfortunately, this results in an additional device to support, along with the increased risk of failure and additional configuration issues.
- Energis are looking to configure the Cisco 1720 routers fitted at the base stations with RS232 cards. This will enable the interface device to be removed from the system, so

lowering the chance of base station failure, and reducing support requirements and costs.

- Router environmental requirements require that they work in the temperature range –6C^o to +60C^o. As the equipment boxes at several locations are in unheated buildings, this has necessitated the need to monitor the performance of each router.
- Hardware infrastructure and services procurement lead times are at least 30 working days.
- As there is no significant advantage in broadcasting data throughout the night for the prototype between the remote sites and the central core, it was decided to offer a 7am – 7pm Monday to Friday testing service. The ISDN lines are set up by a scheduling software package called AT2000 which will open batch files to execute ICMP extended pings to the 21 remote sites. The software package then terminates the batch files at 7pm thus closing down the ISDN lines. The router, which governs IP routing over the network, is a Cisco 3640 which in turn connects to a Cisco 3548 switch. The servers that form the Hub all connect into this switch.

4. TESTING THE RTK NETWORK

The main aim of the testing strategy is to try and gauge the quality and availability of the correction and derived position measurement in the field, ie to replicate usage by field surveyors. The test equipment will therefore be the same as the field surveyors would use – Leica SR530 receiver and AT502 (RTK) antenna. At the time of writing (15/01/02), the testing strategy has just begun, this section therefore describes the methods that are to be deployed. It is hoped that this may provide a guide to similar schemes in the future.

4.1 Base Station Positioning and Monitoring

The positions of the base stations are located relative to the 'Active' GPS network in Great Britain. The Active network has been computed daily for over two years relative to a subset of the IGS network using the Bernese v4.2 software, Rothacher and Mervart [1996]. Figure 7 shows the typical coordinate component station repeatability for the network. Two weeks of data are to be collected from each of the new RTK stations and processed again using the Bernese v4.2 software. Once the station coordinates are computed, they are monitored for stability in the station positions – this is very important as the between station integer ambiguities depend on their positional accuracy. Monitoring is carried out using both the

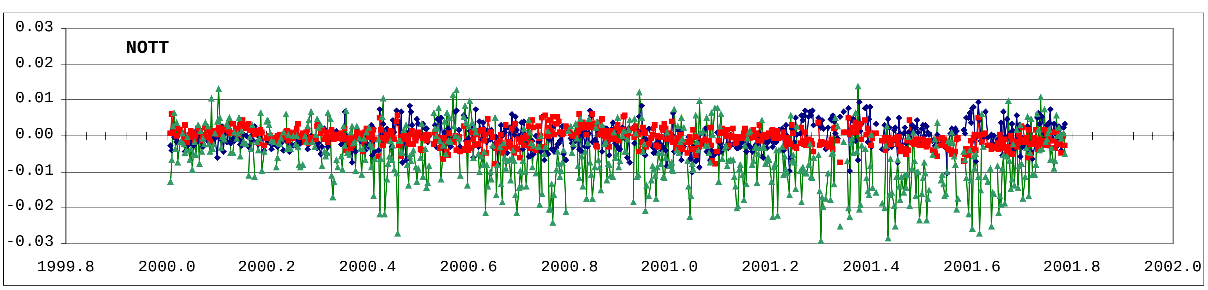


Figure 7. Daily repeatability of station NOTT (Nottingham) in the Ordnance Survey 'Active' network.

Bernese and Geo++ software.

4.2. Testing Strategy

The testing concept prediominantly works on the entire RTK network (figure 2) simultaneously. Testing will be carried out by all parties involved, including Ordnance Survey's two business project partners. The network will also be split into smaller consecutively running networks to look at boundary issues – interference and accuracy. Base stations will be taken out of the solution, for both small and long periods, to check the reliability and robustness of the network and to understand the effect on position availability and accuracy when stations drop out of the solution. Tests will be carried out within the bounds of the network, as well as increasingly outside of it.

The following specific tests are to be performed on the network;

- Time to first ambiguity fix at the rover
- Accuracy (through occupying pre-coordinated points) and precision (through repeatability studies) of position
- The percentage of correct fixes
- Correction signal strength
- Availability of signal
- Reliability of all network components
- Age of correction – latency
- The 'start-up' time of the network – ie when are corrections available from first obtaining raw GPS data at the server.
- Testing the old Ordnance Survey RTK strategy against the new network. Ease of use, accuracy, etc
- Testing external effects on the correction / position, eg ionospheric conditions.

5. CONCLUSIONS

The Ordnance Survey, with its' partners, initiated a project to implement an network RTK solution in the north of England. The project aimed to just as much test the suitability and reliability of the network components as the resultant corrected positions in the field. The network components are now in place and the testing is just starting (15.01.02). If the solution proves successful, and the cost / benefit analysis to the agency is positive, a decision will be made on whether to implement a national RTK network.
The long road to establishing the network has been smooth in places and mountainous in others and this paper sought to describe the process and provide a record of the 'lessons learnt' to help . The main conclusions are to not underestimate the time it takes to complete tasks such as establishing base stations and obtaining radio frequency licences and that the main technical expertise necessary is often in communications, something that is often quite foreign to survey organisations.

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