Trimble

Revolutionary Network RTK Positioning Using Virtual Reference Stations (VRS™)

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September, 2001

1 Introduction

Real-Time Kinematic (RTK) GPS is now widely used for surveying and other precise positioning applications. The classical RTK technique requires that GPS data is transmitted from a single Reference receiver to one or more roving units. Algorithms in the mobile units combine the Reference Station data with measurements from the roving receiver to resolve the integer ambiguity required to calculate precise ranges from the GPS carrier phase measurements. The process of ambiguity resolution is often referred to as "initialisation".

RTK can provide centimetric position accuracy but the accuracy and reliability of the standard RTK solution decreases with increasing distance from the Reference Station. This limitation on the distance between the roving GPS receiver and the RTK base station is due to the systematic effects of ephemeris, tropospheric and ionospheric errors. These systematic errors result in reduced accuracy and increasing initialisation time as the distance between base and rover increases. This restriction is becoming increasingly evident as we approach a maximum in the cycle of solar activity.

A network of reference stations can be used to isolate the components of these systematic errors and use the resultant corrections to create Virtual Reference Stations (VRS) at any location within the Network. Use of a VRS significantly reduces the effects of systematic errors and allows wider coverage, higher reliability, improved accuracy and lower initialisation times than can be achieved by classical RTK techniques.

2 Limitations of Classical RTK Surveying

The restriction in range of classical RTK is due not only to the systematic errors described above but also, in many cases, to the range of available radio telemetry solutions. In practice this means that a temporary RTK base station must be established close to the work area, often at a location that does not provide any physical security or continuous power supply.

Each time such a temporary reference station is established there is an opportunity to introduce an error in the reference station co-ordinates that will be transferred into the position calculated by the rover RTK receiver. Such an error can easily go undetected when using a single base station. In addition to the potential for introducing errors, productivity of the surveyor is lost each time the base station has to be taken down and re-established.

3 The concept of a Virtual Reference Station

Figure 1 illustrates the concept of the VRS. A, B, C and D are GPS Reference Stations. An RTK rover located near the centre of these four reference stations would be affected by systematic errors if using any one of these reference stations. If, however, measurements from these four stations are combined, a model of the geometric and atmospheric errors over the area can be determined and a VRS can be created adjacent to the rover's location, dramatically reducing the systematic errors.

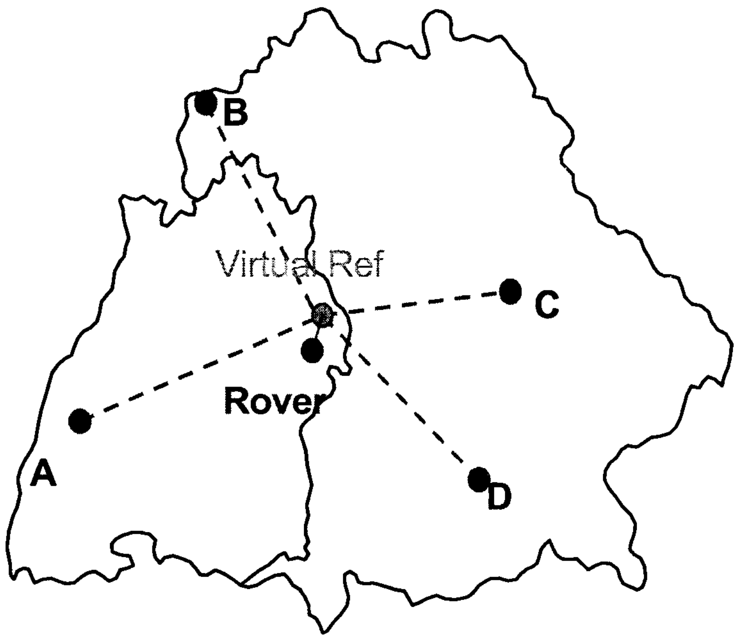


Fig 1. Concept of VRS

4 VRS Network Processes

GPS measurement data from all of the network reference stations are delivered to the network processor each second. For every epoch of data, the network processor performs integrity checks on the GPS observables. For every station and satellite it checks the validity of the ranges. For every station there is a computation of code residuals, an estimation of clock error, rejection of code outliers and cycle slip detection and repair. For every baseline the differential code residuals are computed and outliers are rejected, triple difference carrier phase residuals are calculated, a further cycle slip detection and correction is performed and any phase residual outliers are rejected.

Once the integrity of the data has been checked, the software performs a continuous computation of the following by analysing double difference carrier observations

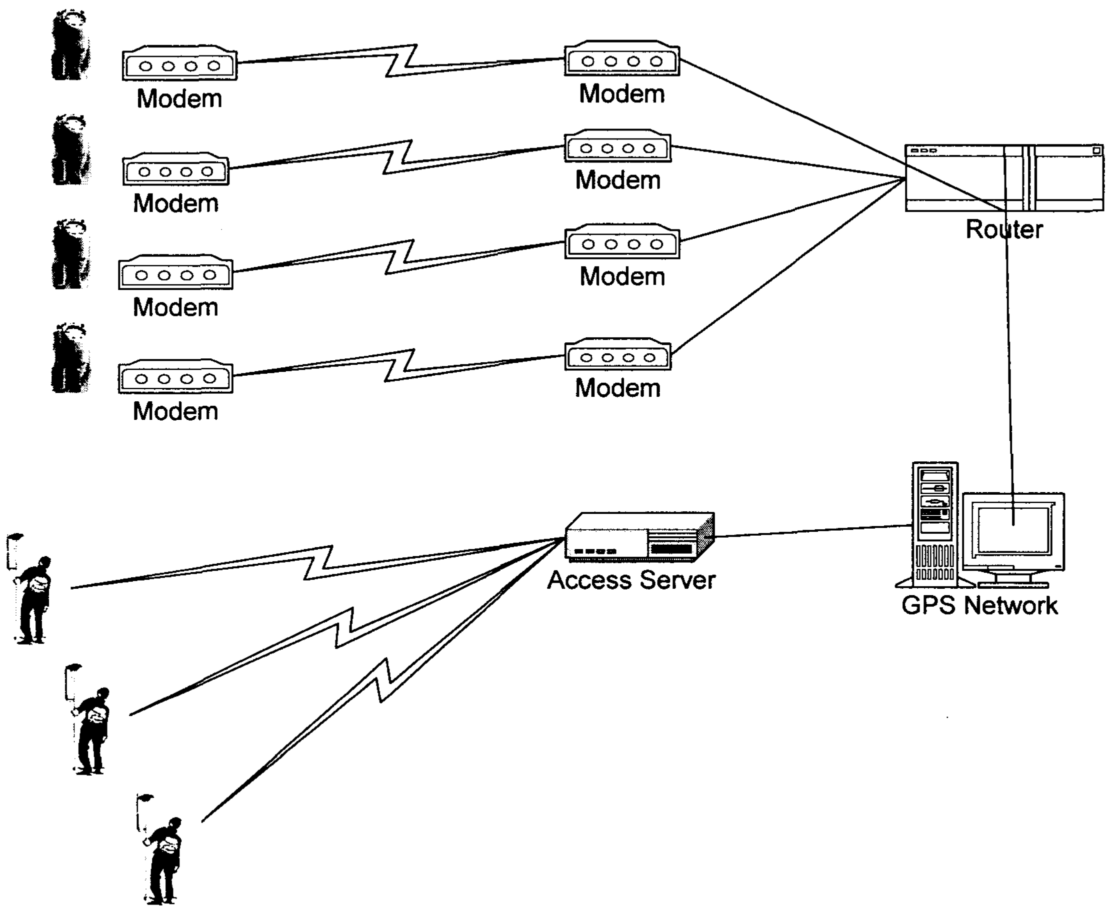
- Ionospheric Errors
- Tropospheric Errors
- Ephemeris Errors
- Carrier Phase ambiguities for L1 and L2

The effect on a rover within the reference station network can be computed from these parameters and so the systematic errors for RTK can be considerably reduced.

To allow this interpolation it is necessary that the rover system provide the approximate position to RTKnet™, the RTK VRS software. This is done using the standard NMEA GGA string, which is supported by most receiver manufacturers. In the past, with Selective Availability (SA) on the GPS signals, an autonomous navigation position could have been in error by hundreds of metres, particularly in height, and so a second iteration using the differential GPS (DGPS) position was used for the location of the VRS data. In the absence of SA, the autonomous position solution is sufficiently accurate for correction of the atmospheric and ephemeris errors from the model.

RTKnet detects incoming calls from rover systems within the reference station network and receives the approximate position. For each location, the RTKnet software selects the nearest reference station, performs a geometric displacement to the location of the VRS, interpolates and applies corrections for ephemeris, troposphere and ionosphere, generates corrected RTCM messages and transmits them to the rover.

Figure 2 provides an example of the data flow within the VRS network.



With these corrected RTCM messages it is possible to perform improved RTK positioning within the network. The expected horizontal position error is 1-2 cm using distances of approximately 50 km between the reference stations.

5 Network Configuration

To transfer the GPS measurement data from the remote stations to the control centre a permanent data channel is required. This can be in the form of a leased line, frame relay or ISDN line etc. Minimum requirement for this connection is 9600 baud with maximum data latency of 1 second. There is no requirement for a PC at the Reference Station, but a PC is sometimes used to facilitate the connection between the GPS receiver and the permanent data line. At the control centre, the incoming data lines are connected to a router. The PC which is running the VRS network software reads the data via IP protocol from the router, i.e. each remote station has it's own IP address. In some cases it is possible to make an arrangement that the telecom company provides the complete functionality of data transfer from the remote sites to the control centre ending in an IP protocol, including all hardware and software required.

The most common method of communication between the RTK rover and the control centre is via GSM or CDMA. GSM/CDMA supports the bi-directional data capability needed to send the user location to the control centre and to receive the VRS RTCM data back from the control centre. GSM/CDMA supports a minimum 9600 baud data rate. Where available the V.110 (ISDN) protocol is preferred. This is a digital format that allows for faster call connections and reliable data transfer. At the control centre, an Access Server with digital modems can service multiple RTK rovers in parallel, each receiving a unique VRS RTCM stream. It is estimated that a single 1 GHz PC at the control centre can service approximately 100 users in parallel. This number can be expanded by using a faster single PC or by employing additional PCs

Examples of national RTK VRS Network for Demark and Switzerland are shown in Figure 3 and 4 respectively.

6 Software Functionality

The network software is available in several levels of functionality. The first level, GPSnet, provides integrity monitoring, cycle slip fixing, data archiving and RTCM data from the nearest (single) Reference Station. Level 2, DGPSnet, adds error modelling for ephemeris troposphere and ionosphere and provides improved accuracy and integrity for DGPS, with Reference Station Spacing of approximately 200km. The highest level of functionality is provided by RTKnet which adds the RTK VRS functionality for networks with Reference Station spacing of 50 – 60km. Reference Station spacing is largely a function of ionospheric activity and can vary from region to region.
In addition, a Webserver package is also available. This allows users to view the network and to download RINEX files for post-processed applications. In addition to the RINEX data stored for each physical Reference Station in the Network, the Webserver can provide virtual RINEX files for any point in the network, using the stored VRS models.

Fig. 3 Denmark VRS coverage map

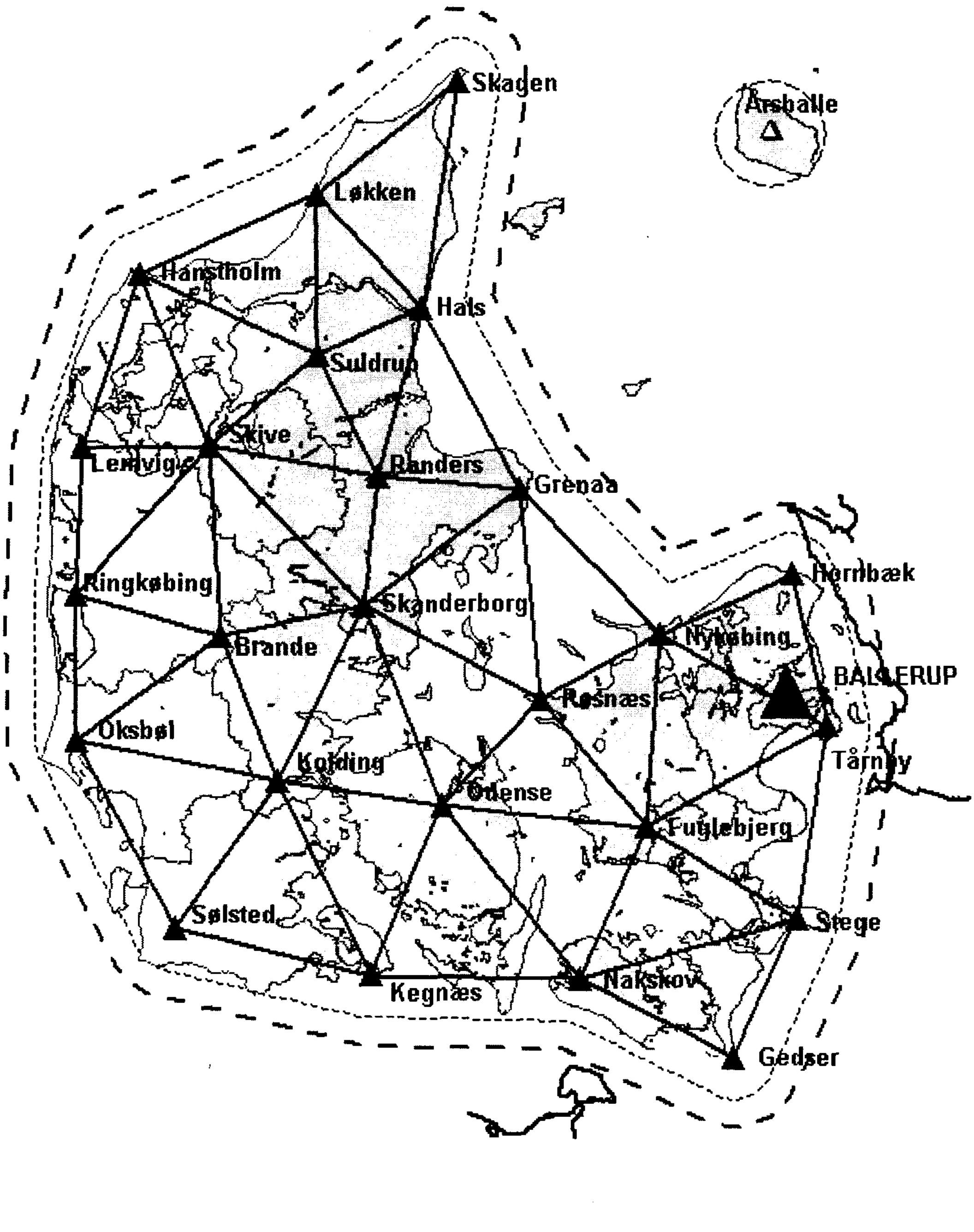
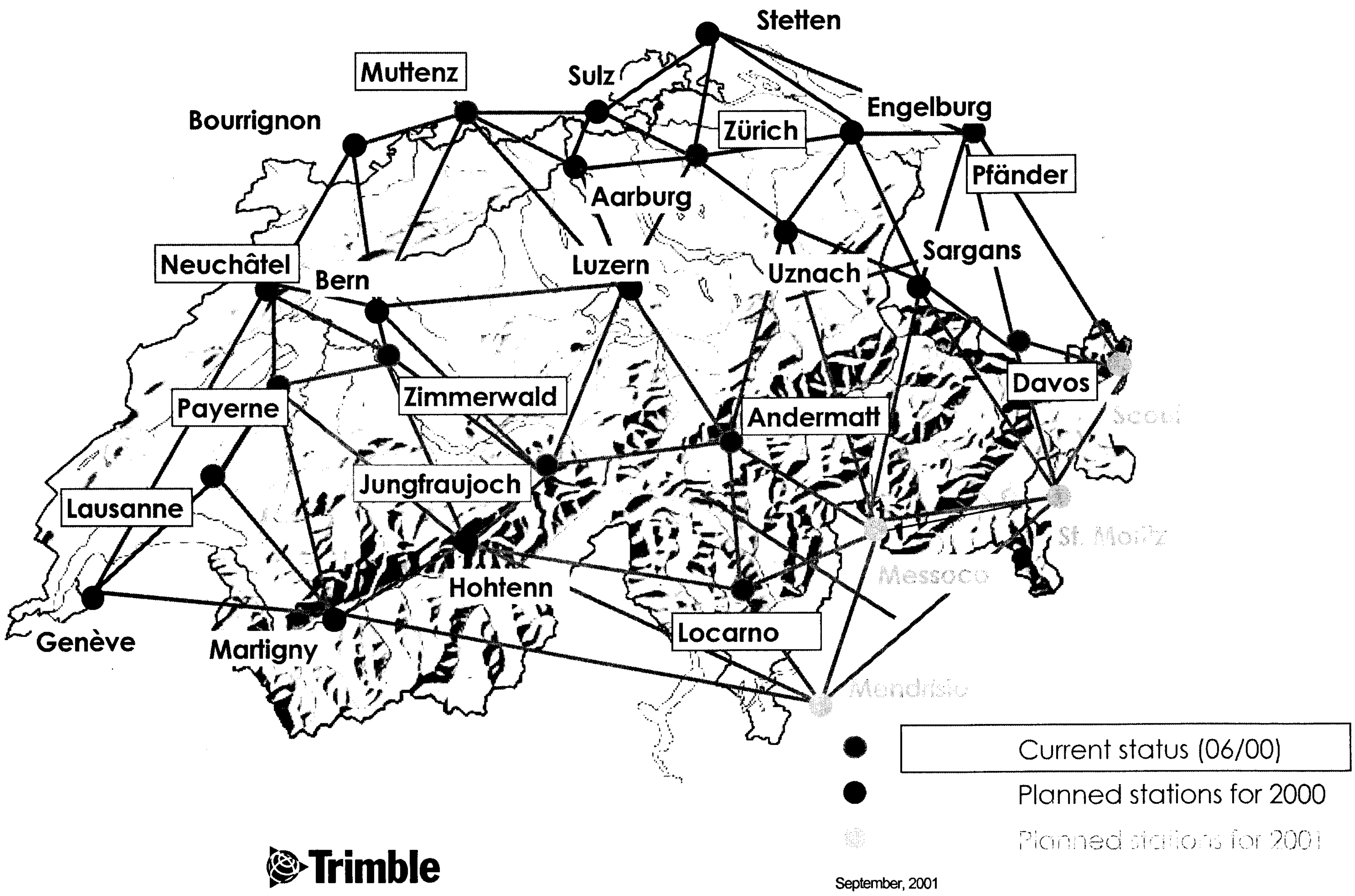
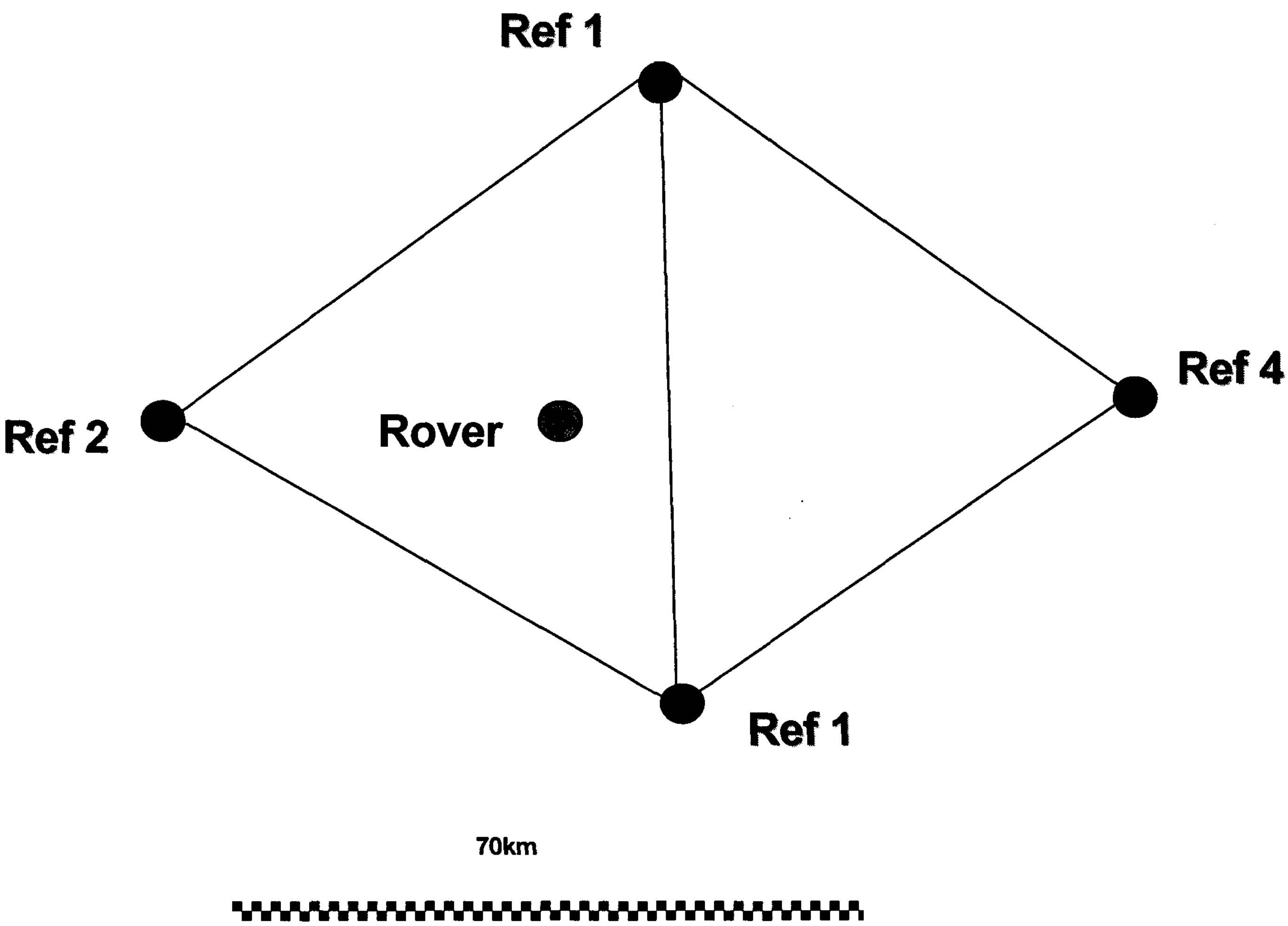


Fig. 4 Switzerland VRS Coverage map



7 Results

Figure 5 shows a network set up near Munich in Germany.



The network shown in Fig. 5 has been used to collect some RTK VRS results. The rover is 32km from the nearest Reference Station. The test was set up so that after initialization, the RTK system output positions for 30seconds. The system was then forced to re-initialise. No data from the past was used. All of the results were stored on a PC for statistical analysis. The results for 90 hours day and night are shown in Figures 6,7,8 and 9.

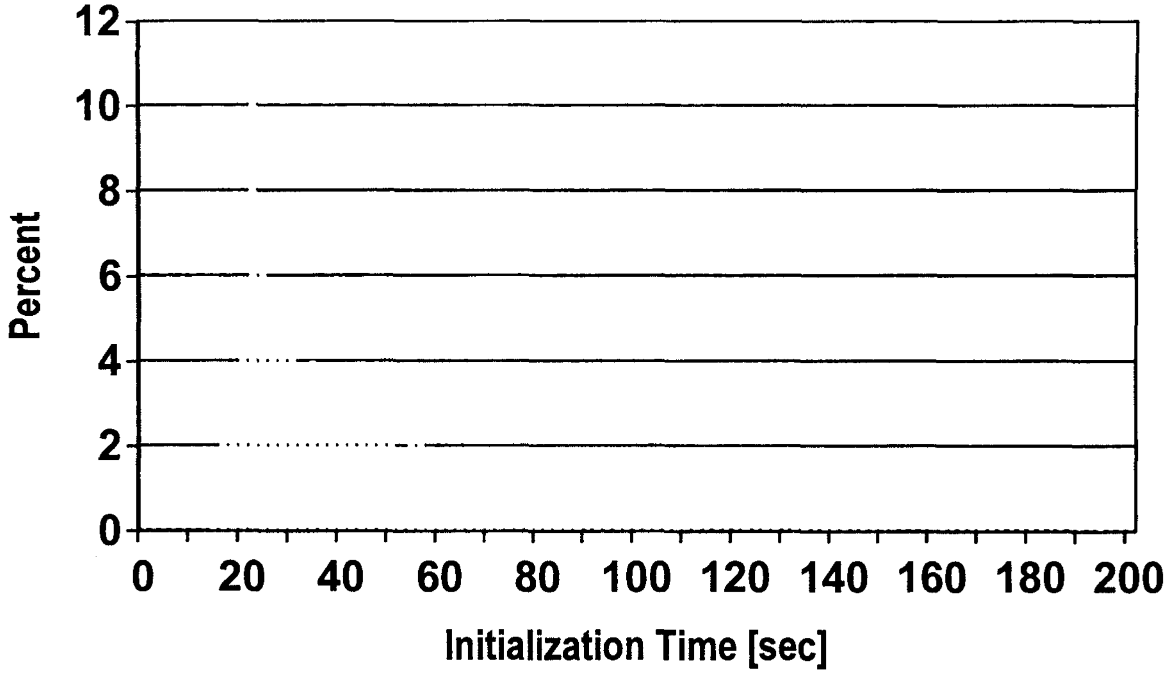


Fig.6 – Initialization times

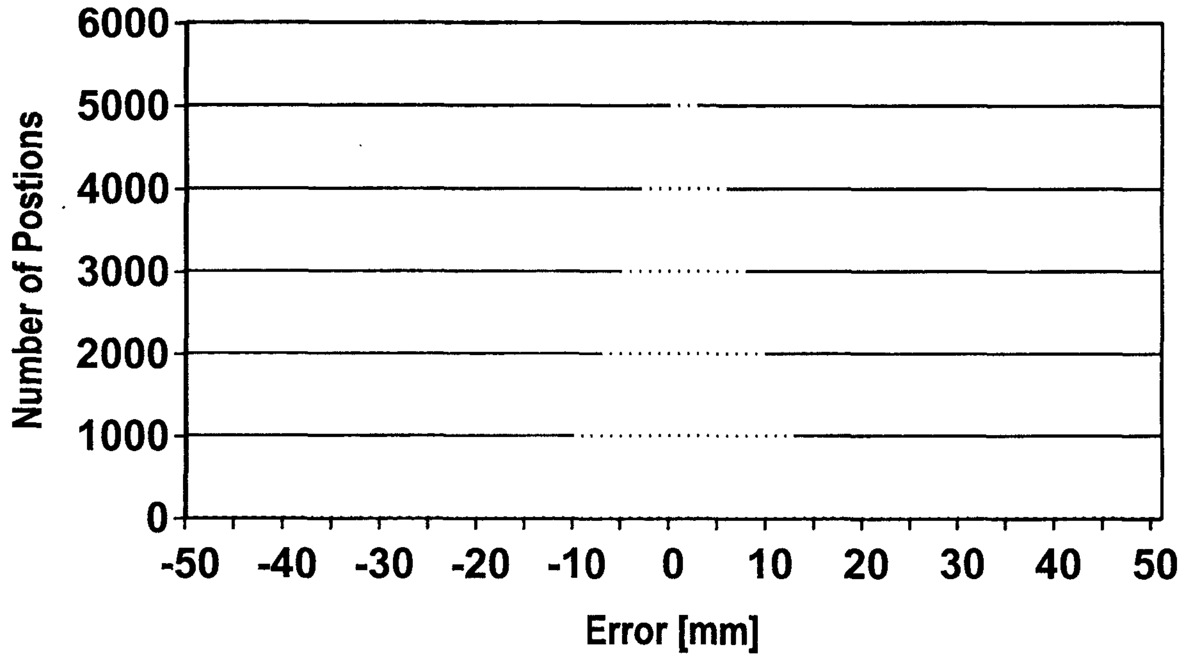


Fig. 7 – North Error

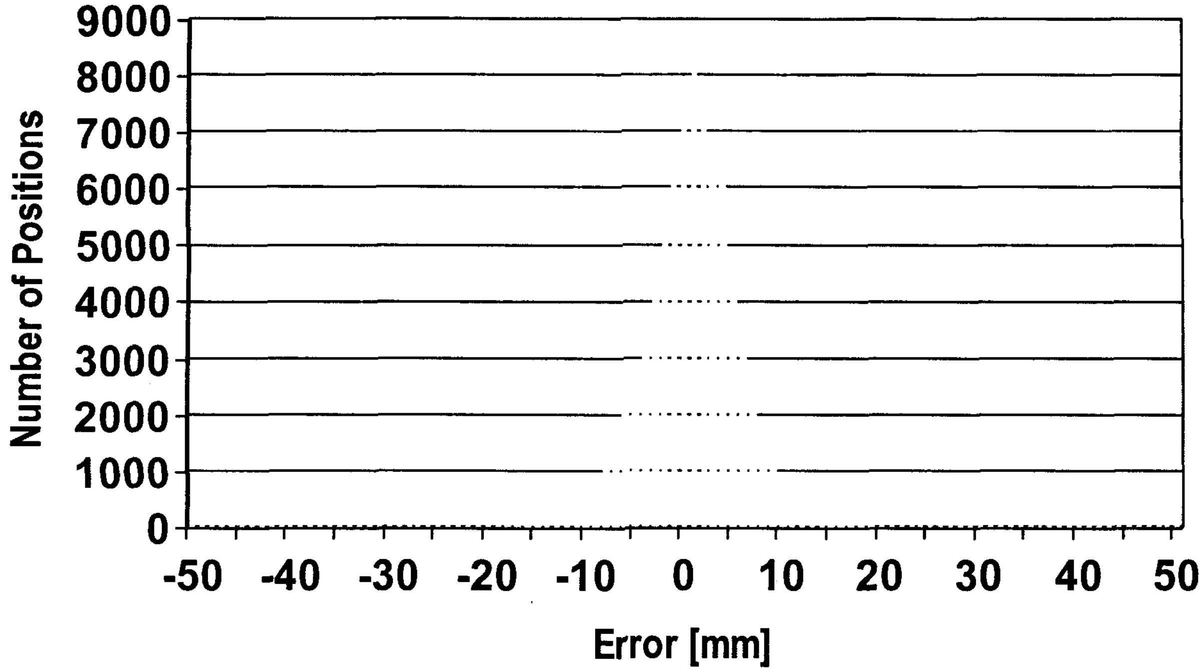


Fig.8 – East Error

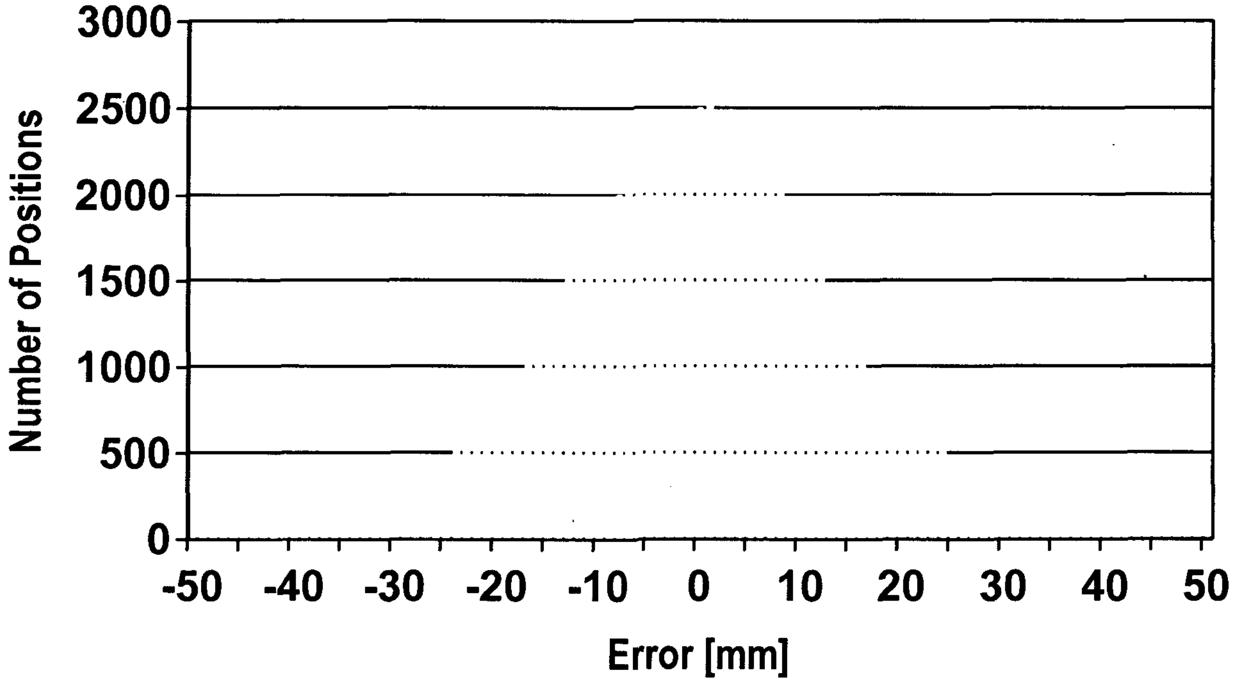


Fig. 9 – Height Error

The results of these tests show that for an effective baseline length of 32km, the mean for initialisation times was 58 seconds with the majority of initialisations taking less than 30 seconds. In addition, 99% of the north co-ordinates were within 26mm of the true position, 99% of the east co-ordinates were within 21mm of the true position and 99% of the results were within 49mm of the true ellipsoidal height. A classical RTK system using a single Reference Station would have difficulty initialising on a 32 km baseline and if it did initialise it would experience errors in the horizontal in the order of 10mm + 1ppm RMS. For a 32km baseline this would equate to a horizontal error of 42mm RMS. The vertical error growth would be in the order of 20mm + 2ppm RMS which would be 84mm RMS over a 32km baseline.

8 Conclusions

The use of a network of GPS Reference Stations to create VRS for RTK has the following advantages over classical, single station RTK positioning:

- Systematic errors are significantly reduced resulting in extended operating range with improved initialisation and accuracy.
- Permanent (or semi-permanent) Reference Stations remove the problems associated with physical security, power supply, environmental conditions and communications.
- Productivity is increased through one person surveying and no time is lost in setting up a Reference Station.
- Integrity of data is continuously monitored before it is sent to the user.
- Potential for gross errors is removed. The co-ordinate frame is established by the network of Reference Stations and network baselines are continuously checked for consistency.

The GPSnet software suite has been installed in Germany, Austria, Switzerland, Denmark, Sweden, Norway, Finland, China, Japan, Australia and the USA.