Presented at ION GPS/GNSS 2003, 9-12 September, 2003, Portland, Oregon, U.S.

SWEPOSä Network-RTK Services – status, applications and experiences

Bo Jonsson, Gunnar Hedling and Peter Wiklund
Lantmäteriet, National Land Survey of Sweden

Abstract

SWEPOS™, the Swedish network of permanent reference stations, is in IOC-mode operation since 1998 and run by Lantmäteriet, National Land Survey of Sweden. Today (August 2003) the SWEPOS network consists of 57 permanent reference stations. The purpose of SWEPOS is to:

- Provide L1 and L2 raw data to post-processing users.
- Provide DGPS and RTK corrections to real-time users.
- Act as high-precision control points for Swedish GPS users.
- Provide data for scientific studies of crustal motion.
- Monitor the integrity of the GPS system.

Today SWEPOS is used as the basis for the Swedish national reference system, SWEREF 99 and besides many surveying and navigation applications also used for meteorology and timing applications.

After pre-studies during the autumn 2000 and the winter 2001, three regional positioning services, based on the Network-RTK concept, are at present (August 2003) in operation. The first Positioning Service, covering the Stockholm area started operation in February 2002, the second service covering the southern part of Sweden in June 2002 and the third one covering the western part of Sweden in September 2002.

Experiences from the Network-RTK concept and design of the services will be shown in the paper. Financial and organizational issues for Network-RTK services will also be discussed.

Examples of the present applications of the Network-RTK services are cadastral surveying, data capture for data bases with position related information and setting out. Expected future applications are e.g. machine guidance and navigation with high precision.

Investigations are on-going for the extension of the Network-RTK services, a preliminary plan for a national Network-RTK service will also be shown.

1. Introduction

The SWEPOS™ network of GPS reference stations began as a co-operation between the National Land Survey of Sweden and Onsala Space Observatory. The early design phases of SWEPOS were made in 1992. It was then stated that the purposes of the network were to be both scientific and of practical benefit to the professional users and the public. The purposes of SWEPOS are to:

- Provide L1 and L2 raw data to post-processing users.
- Provide DGPS and RTK corrections to real-time users.
- Act as high-precision control points for Swedish GPS users.
- Provide data for scientific studies of crustal motion.
- Monitor the integrity of the GPS system.

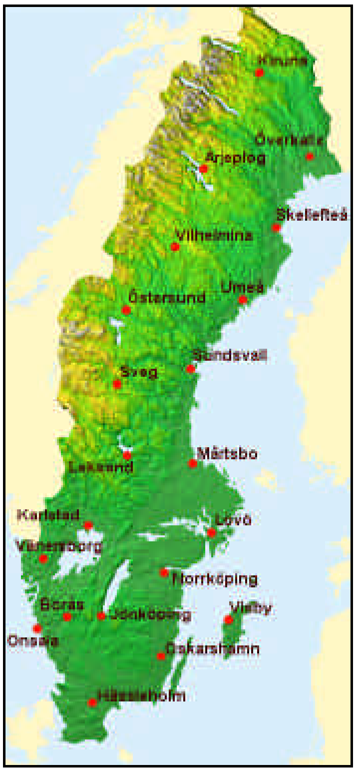

Fig 1. *Design of SWEPOS in 1994*

Today SWEPOS is used as the basis for the Swedish national reference system, SWEREF 99 and besides many surveying and navigation applications SWEPOS is also used for meteorology and timing applications.

At the start in 1994 SWEPOS consisted of 20 stations covering the whole of Sweden with on average 200 km distances between the stations, see figure 1. All the stations were situated on bedrock

The control centre for the network has been located to the National Land Survey of Sweden headquarters in Gävle from the start. In 1996 one more station at the Swedish National Testing and Research Institute in Borås was added. Later several stations aiming to densify SWEPOS mostly for Network-RTK applications have been established.

In 1997 the SWEPOS network was updated with 64 kb leased lines to make it possible to collect all GPS data in real-time. In 1998 the SWEPOS network was declared operational for post-processing applications and support for real-time positioning with meter accuracy, (IOC-mode).

2. Design of the SWEPOS network and data flow

All the SWEPOS stations are connected to a central node, or control centre, using TCP/IP connections. 1 Hz raw observation data and RTCM data (DGPS) are sent via the communication channels to the control centre. The control centre thus has access to all the observations in real time and provides both real time data to distributors and observation data for post-processing directly to the end user.

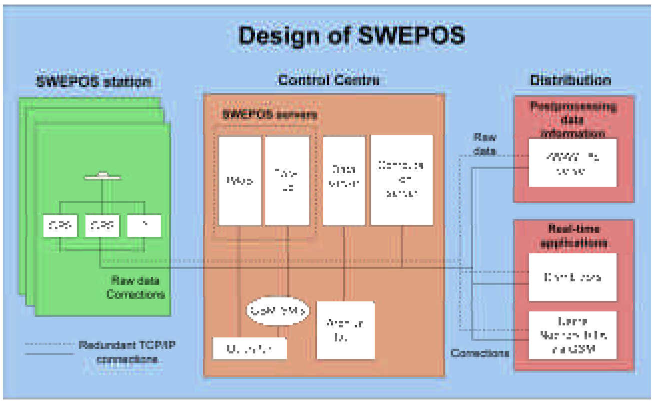

Fig 2. *Data flow in the SWEPOS network*

Currently GPS measurements in Ashtech or Javad raw data format and RTCM message types 1,2 and 3 are transferred in real time via leased lines using the TCP/IP protocol to the control centre at the National Land Survey in Gävle. Data in RINEX format for post-processing can be fetched from the control centre through a WWW/FTP-server. Distributors of real-time DGPS can receive SWEPOS real time corrections in the RTCM format from the control centre via a distribution server and a TCP/IP connection. Network-RTK data is distributed via GSM from the Network-RTK software, which also is connected to the distribution server.

Today the raw data and the DGPS corrections are quality checked at the control centre. Applying the DGPS corrections to raw data from an adjacent reference station and a subsequent position computation and comparison with the known coordinates performs the quality check of the DGPS corrections. The Teqc software is used for quality checking of the raw data.. The design of the SWEPOS-network can be seen in figure 2.

The development from an experimental network to IOC status has been financed by the following governmental agencies: the National Railway Administration, the National Road Administration, the Swedish Civil Aviation Administration, the National Maritime Administration, the Telecommunication Administration, the Swedish State Railways, the Swedish Defence and the National Land Survey. Today the development and operation of SWEPOS are both the responsibility of the National Land Survey.

3. The SWEPOS-stations

In the SWEPOS network the stations are of two types, complete and simplified ones. On the complete stations all equipment is doubled and the stations are mounted on bedrock, while the simplified ones have only one set of equipment and is usually mounted on buildings.

Data is collected from all stations every second and a 5 degrees elevation mask is used. A complete network computation of all the SWEPOS stations is done every day with the Bernese GPS software.

3.1 Complete SWEPOS station

Most of the original 21 SWEPOS stations were built in a similar way. A typical complete SWEPOS station can be seen in the picture below.

Fig 3. *The complete SWEPOS-station Överkalix*

In order to find good bedrock, an undisturbed line of sight to the GPS satellites and safe surroundings, most of the original 21 stations are situated in the countryside of Sweden.

A three metre high concrete pillar can be seen to the left of figure 3. On the top, a Dorne Margolin antenna is mounted under a radom made of clear acrylic. Due to the winter conditions in Sweden, the pillar is heated electrically to a constant temperature of about 15 °C. To monitor the movements of the pillars, a small precision network is established around the pillar using steel bolts as markers in the bedrock.

3.2 Simplified SWEPOS station

In connection with the development of a Network-RTK-service, additional stations have been established. These new stations are mostly established on the top of buildings, typically belonging to local authorities, see figure 4. Leased lines are also used to connect these stations to the control centre. The positions of the simplified SWEPOS stations are computed daily in the same way and together with the complete SWEPOS stations.

Fig 4. *Simplified SWEPOS-station*

Fig 5. *Instrument rack on the SWEPOS-stations*

The position of the simplified SWEPOS stations are checked daily and time series for their positions will be publish on the SWEPOS Web-site along with time series for the complete SWEPOS stations.

4. The interaction between SWEPOS and EUREF - and IGS sites

The National Land Survey and Onsala Space Observatory has been active for a long time in international projects. The European countries have collaborated in building up a network of permanent GPS stations as well as computing national realisations of the adopted European three dimensional reference system ETRS 89. This work is done under the IAG Subcommission for Europe (EUREF). EUREF is also engaged in the establishment of a common vertical reference system based on the national levelling networks and the European GPS campaign EUVN.

The realisation of ETRS 89 in Sweden is called SWEREF 99 and replaces the earlier ETRS 89 realisation SWEREF 93. SWEREF 99 was (certified) accepted by EUREF in June 2000 and is defined by the 21 complete SWEPOS stations.

The SWEPOS stations Visby, Onsala, Borås, Mårtsbo, Vilhelmina, Skellefteå and Kiruna are included in the European network of permanent reference stations, EPN. Data is delivered every hour to the data centre at BKG (Federal Agency for Cartography and Geodesy) in Germany. Data in the EPN network is processed at a number of analysis centres in Europe and the results from these computations are combined to one solution per week, which is available at the EUREF web-site. The data from the Nordic block of EUREF sites is processed at the Nordic Commission of Geodesy (NKG) processing centre at Onsala Space Observatory and National Land Survey. Visby, Onsala, Borås, Mårtsbo and Kiruna are also included in the network for the International GPS Service (IGS).

5. SWEPOS SERVICES

Data from the SWEPOS network is available for the end-user via the following services:

- Post-processing data through a WWW/FTP service
- An Automatic Computation Service on the SWEPOS Web
- The DGPS-service Epos run by the Swedish company Cartesia
- The global WADGPS-service Omnistar run by the multi-national company Fugro

5.1 Data for post-processing

SWEPOS data is available on a WWW/FTP server in RINEX-format. Quality checked data is available on the WWW/FTP server for download within one hour after the observation on the SWEPOS station. Data is charged according to a subscription system, see www.swepos.com.

5.2 Automatic Computation Service on the SWEPOS Web

The National Land Survey has developed an automated processing service in order to facilitate the use of SWEPOS for high-precision static point positioning. The Bernese GPS software and a web application is used for the computations.

The position for any site in Sweden can be computed by submitting an observation file containing dual frequency data in RINEX format to the Automatic Computation Service via the SWEPOS web-site. When the processing is completed (typically after 5-10 minutes) the Web page is updated and a text file with a summary of the processing is sent to the user by e-mail. The final co-ordinates are delivered in the national reference system SWEREF 99, a realisation of the European reference system ETRS 89. The users have to transform the results to the desired local reference system if this is required.

5.3 The DGPS-service Epos, operated by Cartesia

Epos is a DGPS service operated by the private company Cartesia. Cartesia broadcasts the corrections via the RDS channel on the FM network. An accuracy of 1-2 metre is achievable over most land and sea areas of Sweden.

5.4 The WADGPS-service Omnistar, operated by Fugro

OmniSTAR is an international Wide Area DGPS service operated by the multi-national company Fugro. OmniSTAR uses geostationary satellites for the distribution of the corrections. The elevation to the geostationary satellites is low at high latitudes, which reduce the availability, especially for land applications, in the northern parts of Sweden. An accuracy of 1-2.5 metres is achievable.

6. Network-RTK

During the years 1999-2001 three pre-study Network-RTK projects were carried out, as collaboration projects between Lantmäteriet, local authorities, governmental agencies, universities and private companies, in the region of Gothenburg in 1999-2000, Southern Sweden in 2000 and around Stockholm in early spring 2001, see fig. 6.

The reasons for the big interest in the Network-RTK are the possible advantages that can be gained from the technique:

- Reduced initial costs for RTK surveying since only a single rover receiver is necessary.
- Increased productivity since no temporary RTK base station is needed.
- Minimized distance-dependant errors, meaning faster surveying and more homogenous accuracy.
- Improved integrity and continuity of RTK surveying because multiple reference stations are used.
- Reduced establishment and maintenance costs for agencies responsible for the geodetic reference networks.

Network-RTK can be used for many types of applications e. g. cadastral surveying, collecting data for GIS databases, precision navigation and machine-guiding applications.

The experiences and results of the pre-study Network-RTK projects were promising and in late 2001 it was decided to establish three one-year production projects in the Stockholm area, in the Gothenburg area and in the southern part of Sweden..

7. The Pre-study Projects

The purpose of the Pre-study projects was to obtain experiences of the operation and performance using currently available Network-RTK softwares and to introduce the Network-RTK techniques in the user community.

7.1 Project NeW-RTK

A test network around Gothenburg was used during the year 2000 in the NeW-RTK project, a collaboration project between the National Land Survey, Onsala Space Observatory, the Swedish National Testing and Research Institute and Teracom. Teracom is a government-owned company responsible for radio and TV broadcasting in Sweden. During these tests Network-RTK software from Geo++ (Wübbena, 1996), University of Calgary (Raquet, 1998) and Onsala Space Observatory was tested. For broadcasting of the network corrections the FM-subcarrier DARC was used. Some results from these tests can be found in (Samsioe and Öhman, 2000) and (Lilje, 2000).

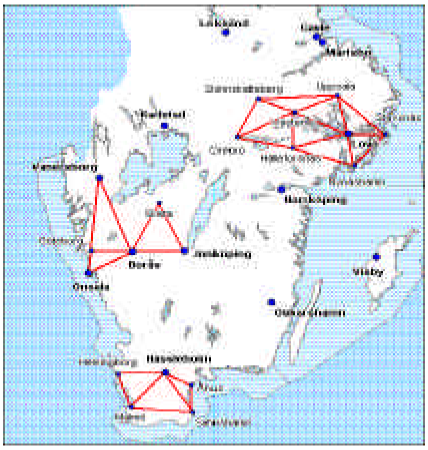

Fig. 6. *The three test platforms for Network-RTK used for the projects NeW-RTK, SKAN-RTK and Position Stockholm Mälaren.*

7.2 Project SKAN-RTK

In the summer 2000 a new Pilot Project, SKAN – RTK, was started with the National Land Survey, Onsala Space Observatory, the Swedish National Testing and Research Institute, the University of Lund, the National Road Administration, National Rail Administration and a number of local authorities in Southern Sweden as partners.

The set up for this project was that real-time GPS-data was collected from three SWEPOS stations and two temporary reference stations to the SWEPOS control centre and entered into the Network-RTK software GPSNet (Vollath, 2000) from Spectra Precision Terrasat (today a part of Trimble Navigation).) This program uses the concept of a Virtual Reference Station (VRS) by which it can get around the problem that there are no Network RTK message. GSM was used as data channel for the communication between the users and the Network-RTK software.

During the first part of the SKAN-RTK project quite a lot of work was needed to adapt some brands of GPS receivers for VRS surveying with GSM modem. The surveying teams in the field had both good and not so good experiences, but all the surveyors who were involved in these projects, were convinced that the Network-RTK concept is a very efficient concept for e. g. surveying of details. Experiences and results from the project SKAN-RTK can be found in (Ollvik, 2001).

7.3 Project "Position Stockholm Mälaren"

During the autumn 2000 a big interest for Network-RTK appeared in the Stockholm area and after some discussions it was decided to start a pilot project in the Stockholm area. The partners in this project were Lantmäteriet, The National Railway Administration, The National Road Administration, Onsala Space Observatory and 11 local authorities. The objective of this project was to establish a Network-RTK test net, using the existing infrastructure SWEPOS with some additional reference stations and investigate the accuracy and functionality of Network-RTK in the Stockholm – Lake Mälaren region. Furthermore we wanted to involve the users in the evaluation of the Network-RTK technique.

Fig. 7. *Map of the Project Position Stockholm Mälaren, test stations are marked with dots*

.

The design of the network of the Network-RTK stations is given in figure 7. Test measurements were carried out during February and March 2001 on about 30, very accurately positioned stations. All test results were done in the reference system SWEREF93[2], the Swedish realization of the EUREF reference system, to avoid any discrepancies caused by transformations between SWEREF93 and local coordinate systems.

The test points were selected to make it possible to study the accuracy as a function of the distance to the closest reference station. The tests were also carried out to see if there existed any technical problems with the Network-RTK techniques. The initialisation time for RTK surveying was measured to investigate the functionality of the technique. By initialisation time for RTK we mean the time needed to fix the integer ambiguities. Five different brands of GPS-equipment were used in the tests: Ashtech Z-surveyor, Geotracer 3200, Leica 530, Topcon Legacy and Trimble 4700/5700.

The RTK test measurements were formed by averaging positions for 30 seconds after all ambiguities had been fixed. Almost 1000 such measurements were carried out on 28 different points. For every measurement the difference between the test result and the true value was calculated. This gives a good measure of the functionality of the technique. Table 1, give a compact summary of the measurements, more details can be found in (Wiklund, 2001).

Tab. 1 Network-RTK measurements February – March, 2001 in the project Position Stockholm Mälaren.

	x=67 %	X=95 %
Largest horisontal deviation in mm of x % of all measurements	16	37
Largest vertical deviation in mm of x % of all measurements	32	91
Longest initialisation time in min:sec of x % of all measurements	00:20	03:30

Network-RTK performed very well during the test measurements with good functionality and initialisation times below 20 seconds for 67 % of all measurements. The test period in February and March coincided with the strongest maximum of the last 11-year ionospheric activity cycle (www.aiub.unibe.ch/ionosphere/meantec.gif). During several days of the tests there were strong indications of an unquiet ionosphere.

We can summarize the findings of the Network RTK pre-study projects in the following way:

- The results were very promising.
- GSM worked very well as a distribution channel for RTK corrections.
- More investigations on Network-RTK software and GPS receiver firmware are required.
- The distance between the reference stations must be shorter than 70 km.
- Prototype production networks should be established.

8. Prototype Production Networks

Based on the experiences and the results from the pre-study projects it was decided in late 2001 and early 2002 to establish one-year production Network-RTK projects in the Stockholm area (Position Stockholm Mälaren 2), in the southern Sweden (SKAN-RTK 2) and in the Gothenburg area (Väst-RTK), see fig. 8. The purposes of the projects were to establish networks of Network-RTK stations, to evaluate function and position accuracy and to get experiences of the use of Network-RTK in different production applications. The following parameters were applicable for the Production networks (projects):

[2] The SWEREF93 reference system was replaced by SWEREF99 in May 2001.

- The Production networks are established as collaboration projects with partners from governmental agencies, universities, local authorities and private companies.
- The existing infra-structure SWEPOS is densified in the project areas
- The partners are financing the communication costs between the project stations and the SWEPOS control centre and 1/5 of the investment costs for the project stations
- Newcomers in the GPS-techniques are offered a two-days course
- Manufacturers of GPS-receivers provides GPS equipment to partners, who don't have their own receivers

The partners in the projects have to pay a yearly fee according to organization size: small organisations 1200 Euros, mid-size organisations 3000 Euros and big organisations 6000 Euros.

8.1 Project "Position Stockholm Mälaren 2"

Following the positive results of the "Position Stockholm Mälaren" project a continuation of the project was initiated. In the new project the number of stations was increased from 8 stations to 21 stations and a much larger area would therefore be covered by the Network RTK service (see fig. 8). Some stations were moved in order to better satisfy the conditions on the distance between the stations (< 70km). GPSNet from Terrasat/Trimble was kept as Network RTK software and GSM as distribution channel.

Tab. 2 Network-RTK measurements 1 February – 1 August, 2002 in the project Position Stockholm Mälaren 2

	x=67 %	x=95 %
Largest horisontal deviation in mm of x % of all measurements	17	38
Largest vertical deviation in mm of x % of all measurements	27	72
Longest initialisation time in min:sec of x % of all measurements	00:17	01:05

Tab. 3 Network-RTK measurements 1 August, 2002 - 1 February, 2003 in the project Position Stockholm Mälaren 2

	x=67 %	x=95 %
Largest horisontal deviation in mm of x % of all measurements	20	39
Largest vertical deviation in mm of x % of all measurements	27	63
Longest initialisation time in min:sec of x % of all measurements	00:17	01:00

The project time for "Position Stockholm Mälaren 2" was one year, starting on February 7, 2002 when the RTK network was declared operational. The number of partners in this project was about 50. Most of these were local authorities but private surveying companies, government agencies and GPS receiver manufacturers are also participating.

Short summaries of results from test measurements in the project area done by the users in the project Position Stockholm Mälaren 2 are given in tables 2 and 3 above. The same kind of routines and statistics, as in chapter 7.3 above, has been used for the carry through of the test measurements. Table 2 gives the result for measurements until August 1, 2002 when GPSNet version 1.56 was used. Table 3 gives the results for measurements after August 1, 2002 when GPSNet version 1.61 was used. Only results from Leica 500 users are used for these summaries.

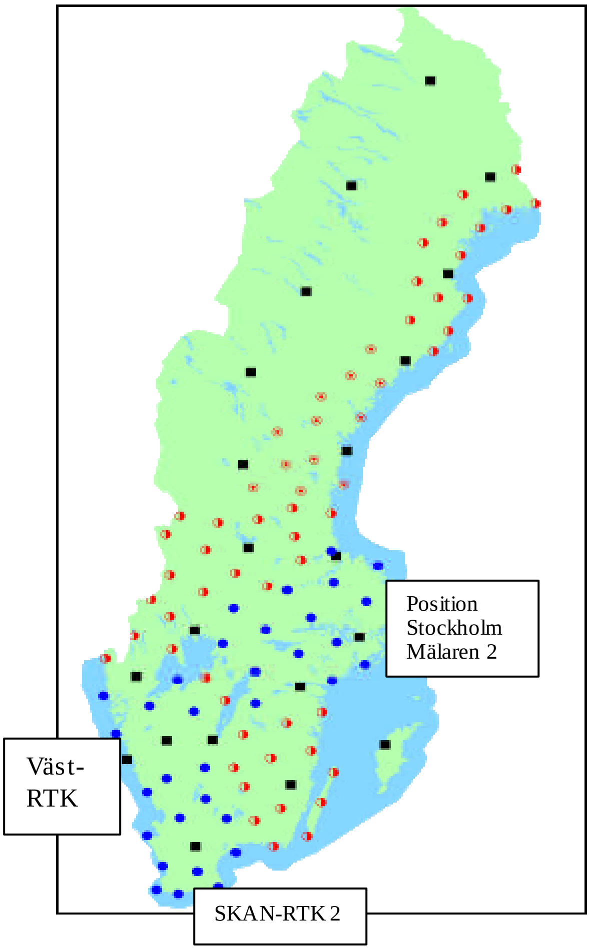

Fig. 8. *Production Prototype Network-RTK projects and a proposal for a National Positioning Service. Filled dots and squares indicate the SWEPOS network today and half-filled dots the future*

From these results it can be seen that the height component and initialisation times have improved compared to the measurements in February and March 2001. This can maybe be accounted to improved adaptation to Network-RTK and the virtual reference station technique in the receiver firmware.

8.2 Project SKAN-RTK 2

Also in southern Sweden the interest of Network-RTK was sufficient for the establishment of a Prototype Production Network, SKAN-RTK 2, see Fig. 8

In this project there are 10 stations and 35 partners. The network became operational on 30 June 2002. In table 4 a summary of the results from test measurements done by the users during the time period October 2002 - April 2003 is shown. The same routines for the test measurements as in the project Position Stockholm Mälaren have been used. An improvement in the height component and the initialisation time can be found.

Tab. 4 Network-RTK measurements during October 2002 – April, 2003 in the project SKAN-RTK

	x=67 %	x=95 %
Largest horisontal deviation in mm of x % of all measurements	17	34
Largest vertical deviation in mm of x % of all measurements	26	53
Longest initialisation time in min:sec of x % of all measurements	00:14	00:42

8.3 Project Väst-RTK

In the project Väst-RTK in western Sweden there are 13 stations and about 35 participants. The RTK network became operational on 22 September 2002. In table 5 a summary of the results from test measurements during the time period December 2002 – July 2003 is shown.

Tab. 5. Network-RTK measurements during December 2002 – July 2003 in the project Väst-RTK

	x=67 %	x=95 %
Largest horisontal deviation in mm of x % of all measurements	15	36
Largest vertical deviation in mm of x % of all measurements	27	71
Longest initialisation time in min:sec of x % of all measurements	00:13	00:40

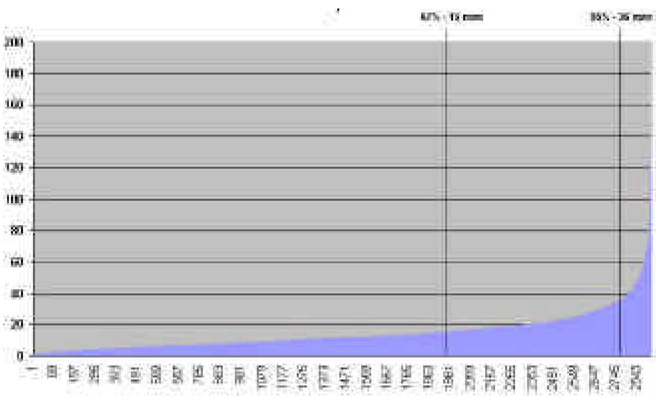

Fig. 9. *Horizontal deviation in mm from the true position, sorted from smallest one to largest one.*

More statistics from the Väst-RTK project during the time period December 2002 – July 2003 are given in the figures 9-12, which show the horizontal and vertical deviations in mm from the "true position" of all carried through test measurements. The diagrams have a mark at the 67% and 95% probability level. Fig 10 and Fig 12 show the horizontal and vertical deviation in mm, with respect to the distance to the closest reference station. The diagrams indicate that there are no significant systematic errors in the Network-RTK positions and that the distant dependant errors are very small.

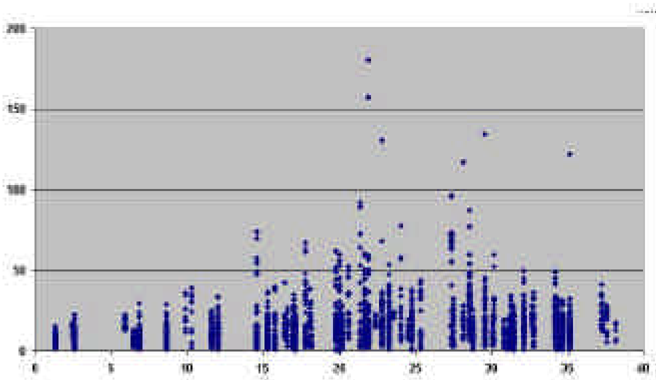

Fig. 10. *Horizontal deviation in mm from the true position, with respect to the distance to the closest reference station*

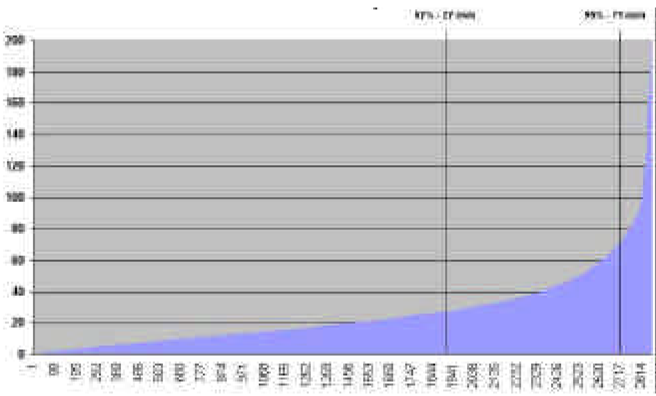

Fig. 11. *Vertical deviation in mm from the true position, sorted from the smallest one to the largest one.*

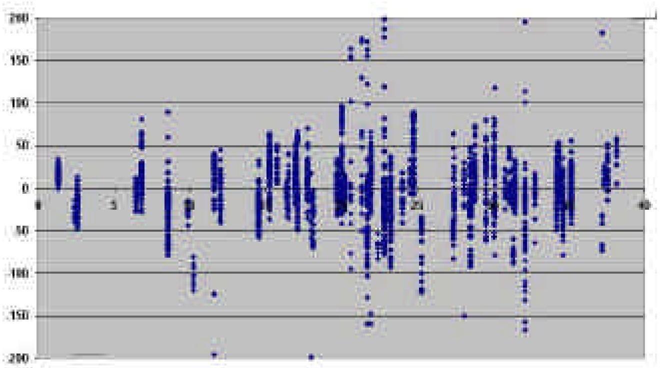

Fig. 12. *Vertical deviation in mm from the "true" position with respect to the distant to the closest reference station.*

8.4 User experiences

To the three Prototype Production Networks there are about 150 connected GSM telephone numbers. The experiences from these users are given below:

- Network-RTK is efficient and easy to use, only one receiver (the rover) is needed for positioning with centimetre accuracy
- It is an advantage to obtain the position directly in a national homogeneous reference system, if the position shall be used in a local reference system, transformation parameters are available.
- The "GPS maturity" of the users is varying, some users have experiences of single station RTK measurements for several years and other users are newcomers and started to use GPS just when the projects were established.
- In each project one start-up day and two user seminars have been arranged for the field surveyors. The steering Committee for each project has had a meeting once every three months. These activities are appreciated as forum for exchange of experiences
- Improved precision (especially in height) and reliability are required for some applications, e. g. machine guidance and setting out for building elements.
- A high availability of the Network-RTK service is required in order to be attractive for potential users.
- Information about interruptions of the Network-RTK service via sms messages on the cellular phone is appreciated.
- The coverage of suitable distribution channels is a bottleneck in some areas. A service provider, who can offer a combination of cellular phone and the DARC channel on the FM-radio network, could improve the coverage of the distribution of Network-RTK data.
- The existing standard formats (RTCM and NMEA) can be used for the VRS-mode (Virtual Reference Station) but there is still a lack of standard formats for the broadcasting of Network-RTK data. The inclusion of a Network-RTK mode in all brands of GPS receivers is also desirable.
- Many of the users would miss the Network-RTK service if it was terminated.

8.5 Network-RTK applications

Up to now the Network-RTK service has mainly been used for the surveying of borderlines and border markers for property and for data capture to data bases, which contain position related information, e. g. geographical information. Setting out is another application in the Prototype Production Networks. Future potential applications are machine guidance and high precision navigation. Other possible future applications are machine steering without drivers in agriculture and forestry.

8.4 Statistics of the connection time in the Network-RTK projects

When a user connects to the Network-RTK software he dials through an Access server, which is connected to the server on which the Network-RTK software is run. The telephone number and the time for the connection are recorded. Weekly diagrams for the total connection time in each project and the connection time for each partner are developed and put on the SWEPOS webpage. The total connection time and number of telephone calls for each project are accessible for all who log in on the SWEPOS Web-site, but the corresponding information for a partner is only available for the partners in the same project. An example of user statistics for the Prototype Production Network Väst-RTK during the time period January –August 2003 is shown in figure 13. Each column shows the total connection time for the users in the project for one week.

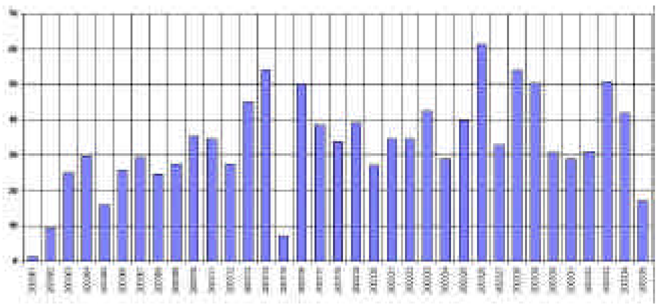

Fig. 13. *Weekly total connection time in hours in the project Väst-RTK during the time period January – August 2003.*

9. Nordic Positioning Service

A task was given to the Nordic Geodetic Commission by the Directors General of the Nordic Mapping Authorities in January 1999. The task was to establish a Nordic project for the development, establishment and operation of a service for positioning and navigation in the Nordic area. In January, 2000 a proposal for a two years development project on a Nordic Positioning Service was presented for the Directors General. The proposal was approved and the Directors General signed an agreement, which included external funds in the fall 2000.

External funds have not been obtained and therefore a reduced project is going on. Up to now the collaboration work between Denmark, Norway and Sweden has been focused on exchange of knowledge, development of an agreement on exchange of data between the existing networks of permanent reference stations. A Nordic Web-portal for post-processing data has been developed and a computer network between the control centres of the Nordic networks of permanent reference stations has been established. A Network-DGPS service with decimetre accuracy, covering Denmark, Norway and Sweden is under development.

10. A National Network-RTK Positioning Service

10.1. A plan for a National Network-RTK Service

In the report Geodesy 2000 a plan for a national Network-RTK service was presented. An additional number of 56 stations are required to cover the most "active" areas of Sweden, see figure 8. The investment cost is estimated to be about 4 million Euros and the yearly operation costs including future upgrades of equipment and maintenance is estimated to 2.5 million Euros. It is proposed that the investment costs shall be covered by governmental funds and that user fees shall cover the main part of the operation costs, the proposal has been submitted to the Director General of National Land Survey for consideration.

10.2. The introduction of a Regional Network-RTK service on 1 January, 2004

During late 2002 and early 2003 the partners in the on-going Prototype Production Networks agreed to extend the project period to 31 December 2003. On 1 January 2004 a Network-RTK service is planned to be in operation in the area, which has been covered by the Prototype Production Network-RTK networks. Cellular telephones will be used for the distribution of the Network-RTK corrections. A user unit is defined as a GSM sim-card with a specified telephone number as an identity. The partner fees will be replaced by user fees, which shall give a contribution to the operation costs. At present (Aug. 2003) the following design of the user fees is discussed:

- A starting fee of 1 000 Euros when you sign for the subscription A or B.
- Alternate A. 2000 Euros/year/ user + GSM charges for unlimited amount of data, i. e. unlimited connection time to the Network-RTK server
- Alternate B. 500 Euros/year/user + 0.4 Euros/min +GSM charges, i. e. the user will pay for the connected time to the Network-RTK server.

We expect to have 200 users connected to the Network-RTK server early next year. In five years we expect to have 1500 users, when the service has been established according to the plan in chapter 10.1.

10.3 Establishment projects

We will continue the work to find financing for the start of the establishment projects in the southeastern, middle and northeastern Sweden. The establishment projects are very important in the interaction with the user community concerning the extension of the Network-RTK service.

11. Conclusions

Projects aiming to develop the RTK methods have been going on in Sweden since 1995. In the early projects single station RTK, radio links and the FM-subcarrier DARC was mostly used. In 1999 the Network-RTK techniques was introduced and we started to use GSM as distribution channel. GSM though, has a weakness in lacking coverage in some regions. An optimal solution would be to combine GSM with the broadcasting of RTK corrections on some alternative data link, possibly DARC. The promising results and experiences acquired in the "Prototype Production Projects" lead us to believe that a position service covering the more densely populated areas of Sweden seems beneficial both for the users and for National Land Survey, as provider of infrastructure for positioning and navigation.

13. References

Geodesi 2000 – svensk geodesiverksamhet under kommande tioårsperiod, LMV-rapport 2001:1, Gävle 2001

Hedling et al. (2001): SWEPOS™ - the Swedish network of permanent GPS reference station (status February 2001), Presented at FIG Working Week, 6-11 May 2001, Seoul, Korea

Jonsson B. et al. (2002): Nordic Geodetic Commission - a successful collaboration between the Nordic countries in the field of geodesy, FIG XXII International Congress, Washington, D.C. USA, April 19-26 2002

Lilje C. (2001): Projekt NeW-RTK – en utvärdering av programvaror för nätverks-RTK. Sinus 2001/1

Raquet J.F. (1998): Development of a Method for Kinematic GPS Carrier-Phase Ambiguity Resolution Using Multiple Reference Receivers, University of Calgary, Calgary.

Samsioe J. & B. Öhman (2000): Testplattform för nätverks-RTK i syfte att ge en rikstäckande GPS-tjänst med centimeternoggrannhet. Institutionen för väg- och trafikplanering, Chalmers Tekniska Högskola, Göteborg.

Wahlund S. (2002): Production measurements with Network RTK – Tests and analyses, LMV-rapport 2002:2, Gävle

Vollath U., A. Buecherl, H. Landau, C. Pagels, B. Wagner: Multi-Base RTK Positioning Using Virtual Reference Stations. Proceedings of ION GPS 2000, Nashville, 2000.

Wiklund P. (2002): Slutrapport för projekt "Position Stockholm-Mälaren –1", LMV-rapport 2002:1, Gävle

Jonsson B. et al. (2002): Some experiences of Network-RTK in the SWEPOS™ network, Proceedings of the 14th General Meeting of the Nordic Geodetic Commission, Helsinki

Wübbena G. et al. (1996): Reducing distance dependant errors for real-time precise DGPS. Proceedings of .ION GPS-96, Kansas City.

Biographical Notes

Mr Jonsson is graduated with a B. Sc. in mathematics, physics and astronomy from University of Lund in 1969. Courses in Geodesy at the University of Uppsala in 1974. He is working as GPS Program Manager and Deputy Head of the Geodetic Research Division of National Land Survey since 1996. Mr Jonsson is secretary in the Presidium of the Nordic Geodetic Commission.

Mr. Hedling is a Senior Research Geodesist at the Geodetic Research Division of the National Land Survey of Sweden. He received a M Sc. in applied physics from Lund University in 1986. He has worked with different GPS applications during the last 15 years.

Mr Wiklund is Project Manager at National Land Survey for the Network-RTK Service. He was graduated as diploma engineer in mapping and surveying at the University of Gävle in 1996.