Some experiences of Network-RTK in the SWEPOS™ network

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Abstract

SWEPOS™, the Swedish network of permanent reference stations, is in operation since 1998 and provides data both for real-time and post-processing applications. After pre-studies during the autumn 2000 and the winter 2001, three regional prototype positioning services based on the Network-RTK concept, are at present (September 2002) in operation. The first Positioning Service covering the Stockholm area was in operation on 7th 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 prototype services will be shown in the paper. Possibilities for integration in the Nordic Positioning Service will also be discussed.

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 public:

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

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

At the start in 1992, SWEPOS consisted of 20 stations covering the whole of Sweden with on average 200 km separation between the stations. 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 RTK applications have also been set up. These differ from the original 21 stations in the following ways: The antennas are usually mounted on buildings instead of on pillars on bedrock. The stations only have one GPS receiver instead of two receivers.

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 navigation.

Network-RTK

During the years 1999-2001 three pre-study Network-RTK projects were carried out in the region of Gothenburg in 1999-2000, Southern Sweden in 2000 and around Stockholm in early spring 2001, see fig. 1.

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.
- Minimizing the 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 surveying, for example cadastral surveying, collecting data for GIS databases, precision navigation and machine-steering applications.

The Projects NeW-RTK and SKAN-RTK

The purpose of these projects was to obtain experiences of the operation and performance using currently available Network-RTK softwares.

A test network around Gothenburg was used 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 used. For broadcasting of the network corrections the FM-subcarrier DARC data channel was used. Some results from these tests can be found in (SAMSIOE and ÖHMAN, 2000) and (LILJE, 2000).

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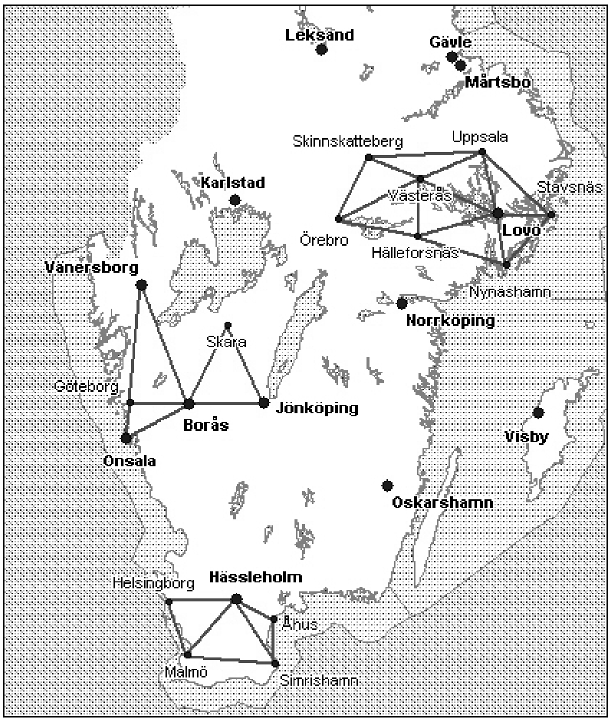

Fig. 1. The three test platforms for Network-RTK used for the projects NeW-RTK, SKAN-RTK and Position Stockholm Mälaren.

In the summer 2000 a new project – SKAN – RTK - was started with the same partners as above except Teracom, also participating in this project were the University of Lund, the National Road Administration, National Rail Administration and a number of local authorities in Southern Sweden.

The set up for these projects was that real-time data was collected from a number of SWEPOS stations and some 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. Instead the user sends his position via GSM to the GPSNet software installed at the control centre. GPSNet then computes corrected RTCM-RTK data valid for the user position (Virtual Reference Station, VRS) that is sent to the user via GSM.

During the first part of the SKAN-RTK project a lot of work was needed to adapt some brands of GPS receivers for VRS surveying with GSM modem. The use of satellite almanacs and predicted ephemeris in the GPSNet software also required some tweaking. The surveying teams in the field have had both good and not so good experiences, but all the surveyors who have been involved in these projects, are convinced that the Network-RTK concept is a very efficient concept for surveying of details.

Project *Position Stockholm Mälaren*

A major obstacle in the earlier Network RTK project had been the difficulty to support projects in the western and southern part of Sweden from Gävle where the National Land Survey is situated, in the middle of Sweden. Therefore during autumn 2000 a new project was started together with a number of municipalities in the Stockholm - Mälaren region as participants, The National Railway Administration, The National Road Administration, Onsala Space Observatory and The National Land Survey of Sweden. The objective of this project was similar to the earlier projects: to investigate the accuracy and functionality of Network-RTK in the Stockholm - Mälaren region. Furthermore we wanted to involve the users in the evaluation of the technique.

A test network was established compromising two permanent SWEPOS-stations, Lovo and Vasteras, and six new project reference stations. The new stations were established in Uppsala, Stavsnas, Nynashamn, Halleforsnas, Orebro and Skinnskatteberg.

Test measurements were carried out during February and March 2001 on about 30, very accurately determined stations. All test results were made using 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 Network RTK. 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.

Practical experiences and results from the project.

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. Figure 3 to 6 below summarize the measurements in the horizontal and vertical components. The plots of deviations against distance to nearest reference station –figure 4 - show that GPSNet almost completely reduces the distance dependant degradation of the horizontal coordinates. For the vertical component – figure 6 – a rather strong degradation with distance still exists. This may be explained by an unquiet ionosphere and the very high electron content in the ionosphere during the measurement period. Figure 7 is a sorted list – re-scaled in per cent - of the initialisation times from the start of the observations until all satellite ambiguities are resolved and fixed in the rover receiver. This gives a good measure of the functionality of the technique. Table 1, give a compact summary of the measurements.

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

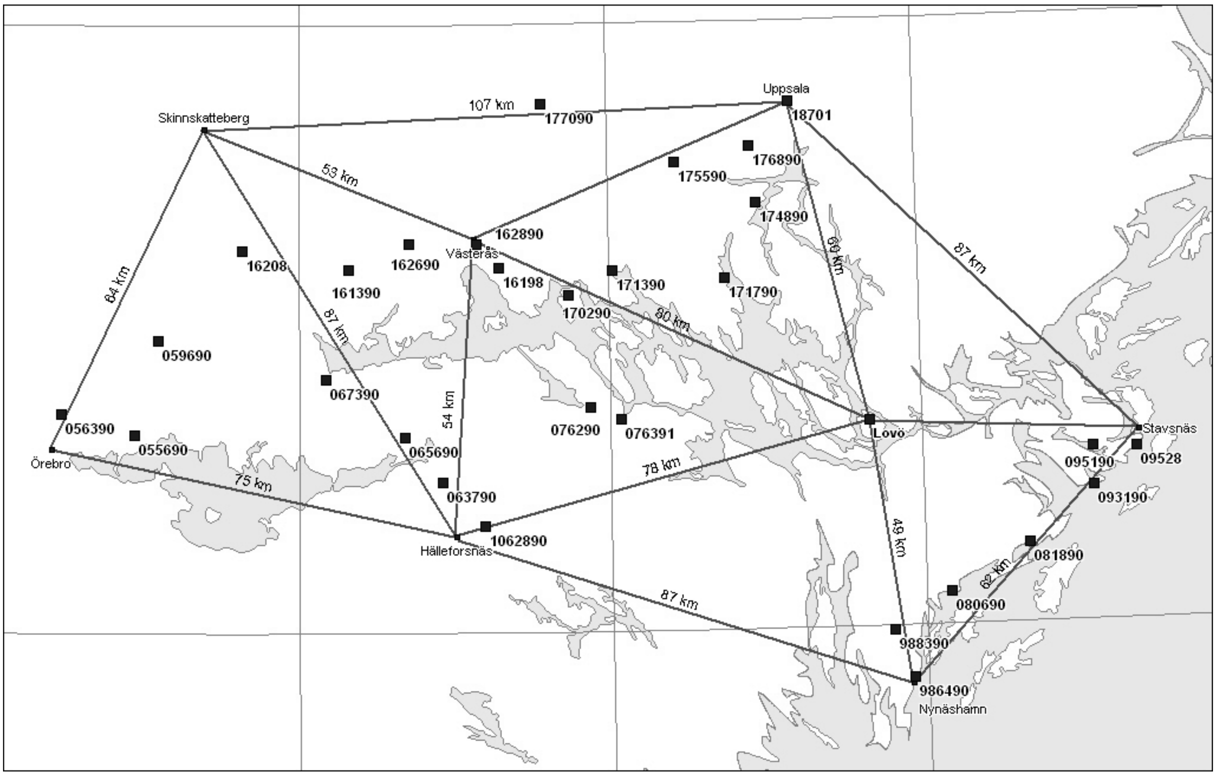

Fig. 2 Map of the Project Position Stockholm Mälaren. Test stations are marked with dots.

Tab. 1

	x=67 %	X=95 %
Largest horizontal 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 projects:

– The results are very promising.
– GSM works 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.

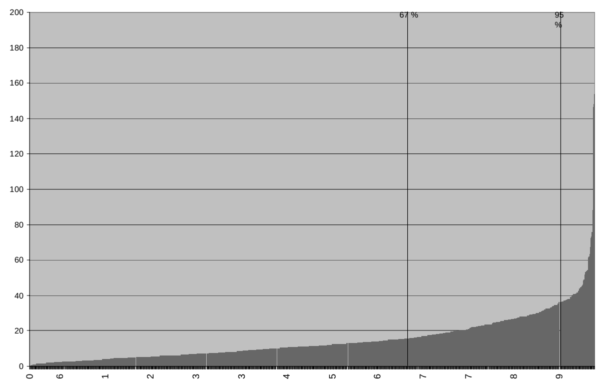

Fig. 3. Horizontal deviations (mm), sorted in order of size, 970 measurements, 20 outliers

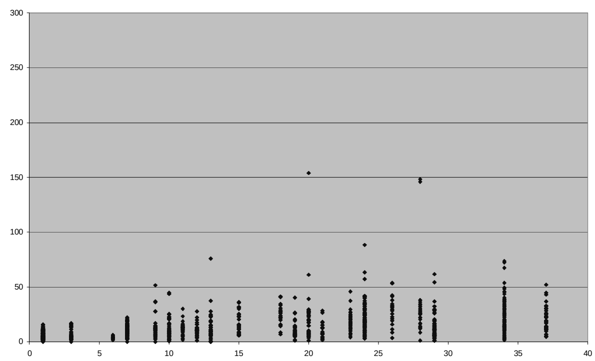

Fig. 4. Horizontal deviations (mm) as function of distance (km) to nearest reference station (970 meas., 20 out)

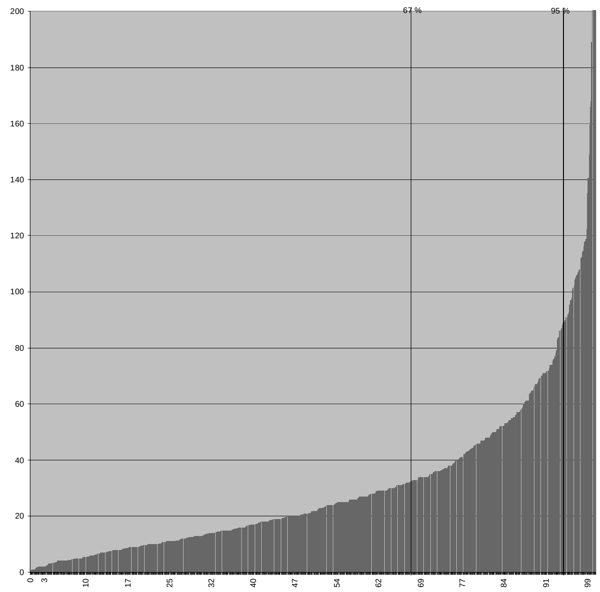

Fig. 5. Vertical deviations (mm), sorted in order of size (893 meas.,15 out.).

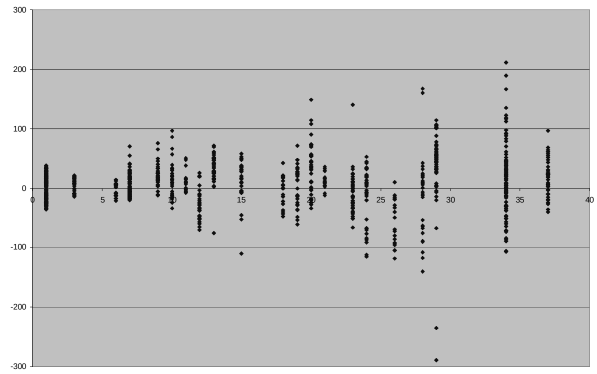

Fig. 6. Vertical deviations (mm) as function of distance (km) to nearest reference station (893 meas. 15 out.)

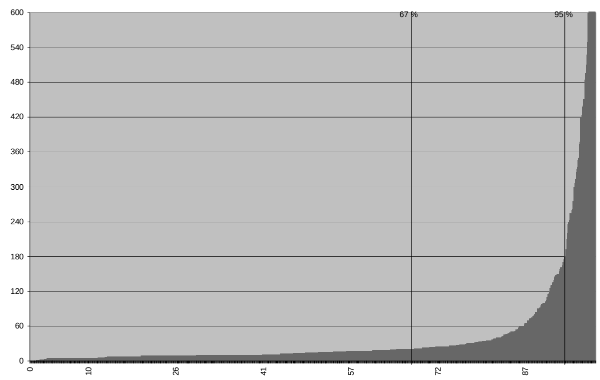

Fig. 7. Initialisation times (sec) sorted in order of speed (970 meas 20 out.)

Project *Position Stockholm-Mälaren*

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 were 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 stations (< 70 km). GPSNet from Terrasat/Trimble was kept as Network RTK software and GSM as distribution channel.

As in the earlier projects, the new project was a co-operation project were the participants get free access to the Network RTK service. The participants have to pay a fee according to organisation size: small organisations 10000 sek, mid-size organisations 25000 sek and big organisations 50000 sek.

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

Short summaries of test results measured by the users in the project are given in tables 2 and 3. Table 2 give the result for measurements until August 1, 2002 when GPSNet version 1.56 was used. Table 3 give 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. From these results it can be seen that the height component and initialization times have improved compared to the measurements in February and March 2001.

This can maybe be accounted to improved adaption to Network RTK and the virtual reference station technique in the receiver firmware.

Tab. 2

	x=67 %	X=95 %
Largest horizontal 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

	x=67 %	X=95 %
Largest horizontal 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

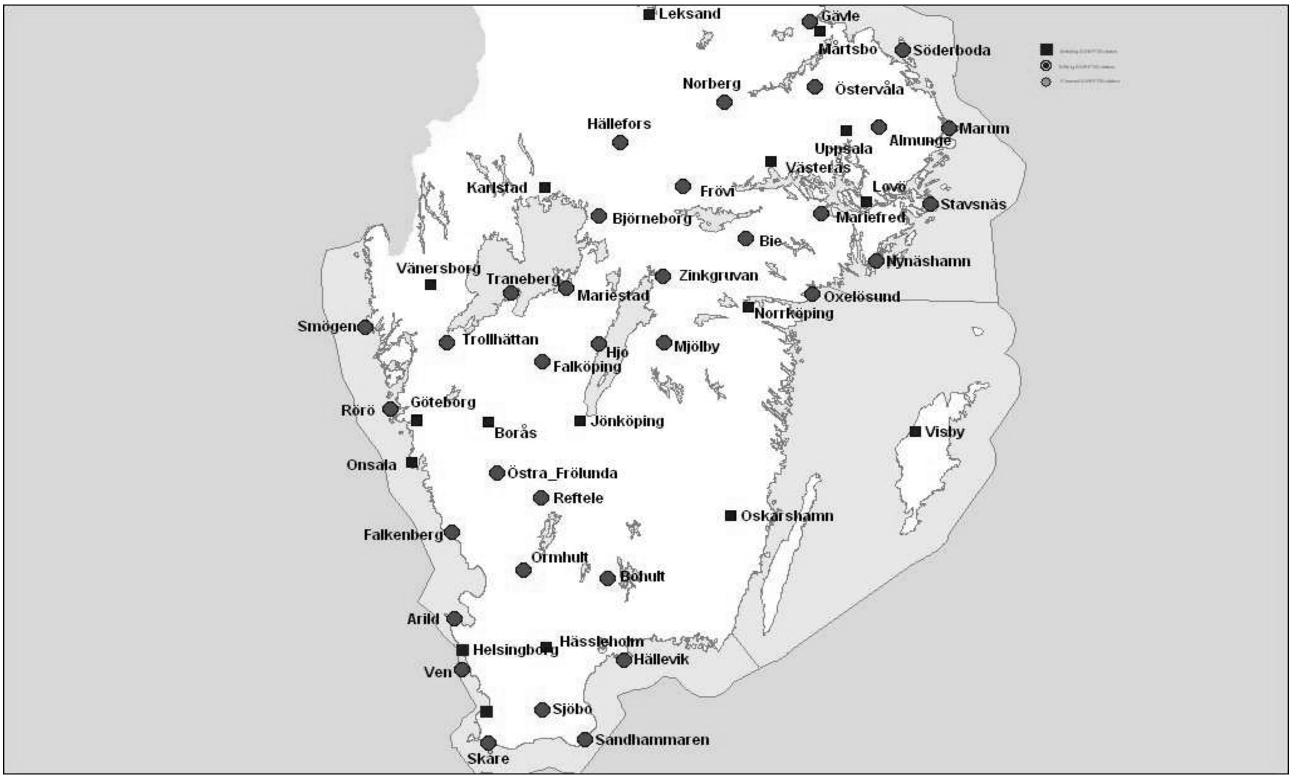

Fig. 8 Older SWEPOS stations (squares) and new RTK stations(rings) in the Southern half of Sweden (spring 2002).

Projects SKAN-RTK 2 and Väst-RTK

Also in Southern Sweden and on the West Coast of Sweden RTK networks have been started (see Fig. 8). In both networks the same kind of project and financing model as in the project *Position Stockholm-Mälaren* is used.

In the project SKAN-RTK in Southern Sweden there are 10 stations and 35 members in the project. This network became operational 30 June 2002. In the project Väst-RTK in Western Sweden there are 13 stations and about 35 participants in the project. The RTK network became operational 22 September.

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 much used. In the later projects that are summarized in this paper, Network RTK and GSM modems are increasingly used. GSM though, has a weakness in lacking coverage in some regions. An optimal solution would maybe be to broadcast RTK corrections with some alternative data link, possibly DARC. Also tests of other Network RTK programs that support a Network RTK message as GNSMART from Geo++.are necessary. The good results acquired in the *Position Stockholm Mälaren* project leads us to believe that a position service covering the more densely populated areas of Sweden seems possible in the near future.

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