Practical Evaluation of RTCM Network RTK Messages in the SWEPOS™ Network

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BIOGRAPHY

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ABSTRACT

Permanent reference stations for GNSS have for a long time been used for positioning of rovers in RTK mode. The RTCM format for transmission of observation data has made it easier to use a variety of GNSS receiver brands.

Ten years ago, work was begun to develop RTCM messages that would contain compressed observation data or models describing the observations from a network of several permanent reference stations. It was self-evident that these RTCM messages should primarily be formed for broadcasting. At the same time server-based systems were developed, where the RTK rovers are sending their positions via NMEA GGA and in return receive synthetic observations from a fictitious reference station. This concept proved to be very efficient and robust, much to the surprise of many people in the surveying and positioning community.

Test measurements with RTK rovers have been performed with the RTCM Network RTK messages 1014, 1015 and 1016 in a 14 station sub-net of the SWEPOS™ network. SWEPOS is the Swedish national network of permanent reference stations for GNSS. The Network RTK server was running Trimble GPSNet and as rovers Trimble R8 and Leica GX1230 receivers have been used. Solutions with Network RTK messages in both static broadcast mode and automatic mode have been compared with standard Virtual Reference Station solutions.

The results from the measurements showed that there were no obvious differences in accuracy between Network RTK messages and Virtual Reference Station solutions. The obtained horizontal accuracies expressed as RMS values of the distribution around the true positions were in the order of 14 millimetres. The differences between static broadcast and automatic mode were also unnoticeable. Concerning the initialization periods for the ambiguity fixed solutions, they were slightly longer for Network RTK messages than for Virtual Reference Station solutions.

Suitable applications for the use of Network RTK with RTCM Network RTK messages are also discussed.

INTRODUCTION

SWEPOS™ is the Swedish national network of permanent reference stations for GNSS (Norin et al., 2008) and the stations are among others used for the SWEPOS Network RTK service. The SWEPOS web-page is found on www.swepos.com. The Network RTK service has approximately 1150 registered users (January 2009) and it is based on the Virtual Reference Station concept. The service uses cellular telephones for the distribution of GNSS data to the RTK rovers in the standardized Radio Technical Commission for Maritime Services (RTCM) format.

Sweden is, from European standards, a large country with big areas that have rather weak cellular coverage. For that reason, alternative distribution channels have been investigated. SWEPOS has a DGPS service (EPOS) since 1994, using the FM-subcarrier RDS. Globalstar (satellite telephone) and CDMA 2000 on the 450 MHz band have been tested. Recently, the Swedish Maritime Administration has also expressed an interest in a RTK Service in the sea around Sweden. The Swedish Maritime Administration is also interested in seamless high-accuracy navigation. The short outages when the Network RTK server re-computes the Virtual Reference Station to follow e.g. a moving ship are not acceptable.

The latest version of the RTCM format (RTCM, 2007) contains a new type of messages; Network RTK messages also called Master-Auxiliary Concept (MAC). In short, these messages consist of compressed observation data from a network of multiple reference stations. Below in this paper results from a test measurement in the SWEPOS network with the new RTCM Network RTK format is presented. The new format is interesting since it is possible to broadcast data to the users. This means that you can cover larger land and sea areas with a RTK service than today with cellular telephones.

NETWORK RTK

RTK surveying in a network of multiple reference stations was pioneered by the work of Gerhard Wübbena in the German SAPOS network (Wübbena et al., 1996). In 1998, a Working Group of the RTCM SC-104 committee was started with Hans-Jürgen Euler from Leica Geosystems as chair-man. The SAPOS approach with area correction parameters (FKP) for ionosphere and geometry was considered to be too model-based for a RTCM standard and instead a more observation-based system was chosen. First a system with grid-based corrections was discussed (Townsend et al., 2000). What was later to be called Master-Auxilliary Concept (MAC) was presented in 2001 by Hans-Jürgen Euler (Euler et al., 2001). Five years later these ideas formed the base of the Network RTK messages in the RTCM standard 10403.1. An interesting

discussion of how the different concepts for Network RTK are related can be found in (Takac & Zelzer, 2008).

The Master-Auxilliary Concept is founded on the idea of using phase **corrections** instead of phase observations because of their greater insensitivity to latency. In a group of reference stations a master station is chosen, the other stations are then called auxiliary stations. Differences of the corrections between master station and auxiliary stations are formed and eventually ionospheric and geometric linear combinations of these are computed. Network RTK messages can be used in both static (broadcast) mode and in automatic mode. In static broadcast mode, the master station is predetermined and in automatic mode, it will be the station closest to the rover. The data can then be sent as RTCM messages 1015, 1016 and 1017. The data types have been chosen so that it should not be necessary to send all messages every second as has become standard in RTK surveying.

The Network RTK messages can be sent to the users with a broadcasting communication link e.g. radio, FM-sub-carrier (DARC or DAB) or Internet broadcast. They can also be sent to the users via two-way data links like, cellular telephone, satellite telephone or wireless Internet.

THE SWEPOS™ NETWORK

The SWEPOS network of permanent reference stations for GNSS is operated by Lantmäteriet, the Swedish Mapping, Cadastral and Land Registration Authority. Today (January 2009), the network consists of 166 stations for both GPS and GLONASS operation, see Figure 1.
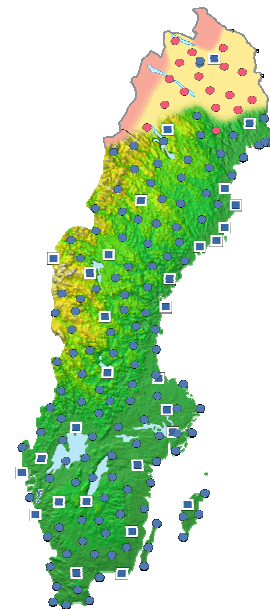

Figure 1: The SWEPOS™ network of permanent reference stations for GNSS consists of 166 stations covering Sweden. Red dots are planned stations.

All SWEPOS stations are connected to a control centre located at the headquarters of Lantmäteriet in Gävle via leased TCP/IP connections. The SWEPOS control centre receives 1 Hz raw GNSS data from all stations in real-time. The data is quality checked before further distribution to different services and end-users. An extension of the SWEPOS network will be carried out during 2009, see Figure 1.

The development of SWEPOS started in 1991 and the network was declared operational for post-processing applications and for real-time positioning with metre accuracy in 1998, IOC mode. Since 1999, improvements have been done to meet demands on real-time positioning with centimetre accuracy. After 2000, both the development and operation of SWEPOS is the responsibility of Lantmäteriet. The development has however been done in co-operation with Onsala Space Observatory at Chalmers University of Technology in Gothenburg and the SWEPOS users.

The 21 SWEPOS stations that were build in the 1990´s are all monumented with concrete pillars directly on bedrock, see Figure 2. These stations are also the basis for SWEREF 99, which is the Swedish national geodetic reference frame. Five of these stations are also included in the network of the International GNSS Service (IGS).

Figure 2: Överkalix is one of the 21 first SWEPOS stations belonging to Class A.

New stations have been added since 1999 and the establishment of most of them has been done in a simplified way. For example, most of these stations have

roof-mounted GNSS antennas, see Figure 3. The first 21 stations together with 11 newer stations that mainly have been monumented with concrete pillars on bedrock are called Class A stations (blue squares in Figure 1). The remaining 134 stations belong to Class B and have mainly been established for Network RTK purposes (blue dots in Figure 1).

Figure 3: Söderboda is a SWEPOS station with a roof-mounted GNSS antenna mainly established for Network RTK purposes belonging to Class B.

Of the different services that make use of SWEPOS data for both post-processing and real-time applications, the SWEPOS Network RTK Service is the one with the greatest number of users. It was launched on January 1st 2004 and the whole country will soon be covered by the service, the coverage area today (January 2009) is shown as the green area in Figure 1.

The SWEPOS Network RTK Service is based on Virtual Reference Station solutions with two-way communication between the control centre and RTK rovers. GSM and GPRS (i.e. mobile Internet connection) are used as the main distribution channels for the real-time GNSS data in the RTCM standard format, version 3.0. The expected position accuracy is approximately 15 mm horizontally (68 %) and 25 mm vertically (68 %). Data from the service is charged according to a subscription system and all data distribution costs are paid by the users to the GSM/GPRS operators.

The number of registered users of the Network RTK service is approximately 1150 (January 2009). There are also about 150 additional licenses used by universities and

GNSS equipment dealers etc. The goal is to have 1500 users within the next three years. The rapid increase in the usage of the Network RTK service is shown by a diagram showing the total user connection time, see Figure 4.
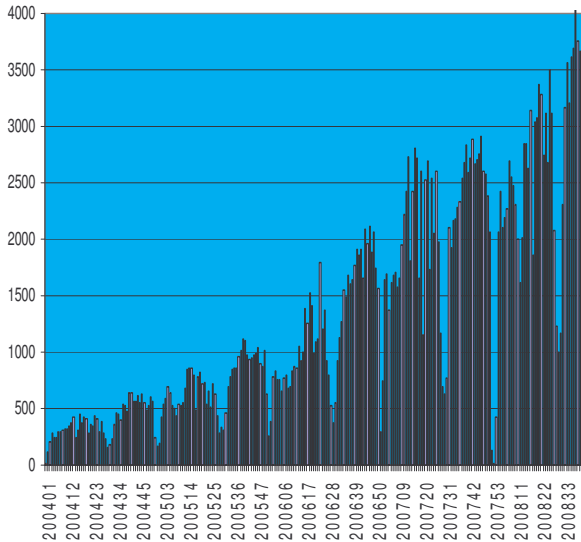

Figure 4: Total user connection time (in hours) per week for the SWEPOS Network RTK Service, from 2004 to autumn 2008.

The Network RTK service is widely used for data capture in mapping applications, but also in several other areas such as cadastral surveying and for building and construction work. Figure 5 shows statistics of usage according to type of business.
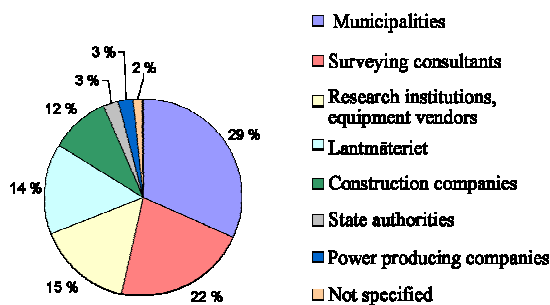

Figure 5: Number of SWEPOS Network RTK Service users per business category (November 2008).

GLONASS TEST IN THE SWEPOS NETWORK RTK SERVICE

After GLONASS data was included in the SWEPOS Network RTK Service on April 1st 2006, the performances of the service with and without GLONASS were compared in a diploma work (Johnsson & Wallerström, 2007).

A total number of 1440 measurements were made in the diploma work with three different brands of RTK equipments on points with large variations in visibility towards the satellites. Three things were studied in the measurements:

- Successful measurements.
- Differences between measured and known positions.
- Times to fixed ambiguity solutions.

A measurement was considered to be successful if a fixed ambiguity solution was obtained within three minutes. The combination GPS/GLONASS gave more successful measurements than only GPS, see Table 1. Concerning accuracy expressed as RMS values of the differences between measured and known positions, only GPS showed slightly better values than the combination GPS/GLONASS. This can however be explained by the fact that there were more successful measurements with the combination GPS/GLONASS, and that these measurements were taken during rather bad conditions.

Table 1: Number of successful measurements and RMS values of the differences between measured and known positions for the successful measurements.

	Successful measurements	RMS horizontally	RMS vertically
GPS/ GLONASS	89 %	16 mm	24 mm
GPS	82 %	14 mm	21 mm

To summarize, the combination GPS/GLONASS showed better performance than only GPS in the SWEPOS Network RTK Service, but the accuracy was on the same level.

TEST MEASUREMENTS WITH RTCM NETWORK RTK MESSAGES

Test measurements with RTK rovers have been performed during the spring 2008 with the RTCM Network RTK messages 1014, 1015 and 1016 in a 14 station sub-net of the SWEPOS network (Johansson & Persson, 2008). The measurements were done on three points called A, B and C with accurate positions in SWEREF 99, see Figure 6. These positions have been considered as known in the study.
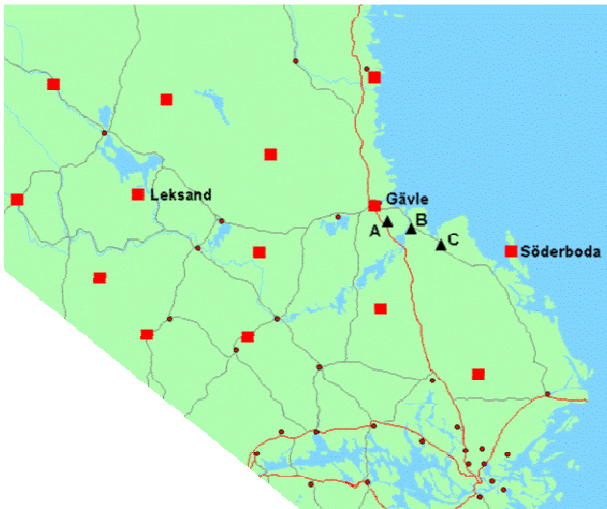
Figure 6: The 14 station sub-net of SWEPOS (red squares) and the three points (A, B and C) that were used for the test measurements. Scale approximately 1:4 000 000.

The Network RTK server for the SWEPOS Network RTK Service is running Trimble GPSNet and this software was also used in this test. GPSNet (version 2.60) was configured to send ionospheric correction differences (msg 1015) for all stations every second and geometric correction differences (msg 1016) for three stations every second. This means that the latency for the geometric messages was 4-5 seconds! The reason for this setting was that we also wanted to do a simple test of the RTCM Network RTK messages data compression capabilities!

For the communication between the RTK rovers and the SWEPOS server, mobile Internet (GPRS) was used. Only GPS was used in the test because the GLONASS RTCM Network RTK message standard is not ready yet. Trimble R8 (firmware 3.60) and Leica GX1230 receivers (firmware 5.62) were used as rovers. Solutions with Network RTK messages in both static (broadcast) mode and automatic mode and also based on standard Virtual Reference Station solutions were obtained with four different methods:

- Network RTK messages in static broadcast mode with Gävle as master station.

- Network RTK messages in static broadcast mode with Leksand as master station.

- Network RTK messages in automatic mode with the closest SWEPOS station as master station.

- Standard Virtual Reference Station solution.

This means that the measurements on point A and B in automatic mode had Gävle as master station and that measurements on point C in automatic mode had Söderboda as master station. The distances from the points A, B and C to the SWEPOS stations that have been used as master stations are shown in Table 2.

Table 2: Distances from the points A, B and C to the SWEPOS stations that have been used as master stations.

Point	Gävle	Leksand	Söderboda
A	10 km	131 km	65 km
B	22 km	143 km	53 km
C	40 km	160 km	36 km

The measurements were carried out under varying satellite conditions during 12 different days and done with the GNSS antennas attached to a tribrach on a tripod. The satellite cut-off angle was set to 13° above horizon. A total number of 150 measurements were done evenly spread over the three points with each of the four methods and with each of the two receiver brands. In this way, totally 1200 measurements were performed, where each measurement was a mean value of five successive observations. There was however some uncertainties about the settings used in the receivers for the measurements. One of these uncertainties concerned the distance threshold to the master station in the Leica receiver; it was probably set to low and as a result it had problems to resolve the ambiguities with Leksand as master station. Regardless of what settings caused the problems, these measurements were cancelled and the final number of measurements was therefore 1050. Of these 1050 measurements, 1036 were successful (99 %). A measurement was considered successful if a fixed ambiguity solution was obtained within three minutes!

RESULTS FROM THE TEST MEASUREMENTS WITH RTCM NETWORK RTK MESSAGES

Results in the horizontal component from the test measurements with the four different methods are presented in Table 3 and results in the vertical component are presented in Table 4. Only successful measurements are included in the results.

Table 3: Results in the horizontal component.

	Mean deviation	Max deviation	RMS
Gävle	6 mm	48 mm	14 mm
Leksand[*]	7 mm	39 mm	15 mm
Auto	6 mm	43 mm	13 mm
VRS	8 mm	45 mm	13 mm

[*]The values for "Leksand" are only based on measurements with the Trimble receiver.

In the tables "Mean deviation" shows the mean values of the deviations from the true positions, "Max deviation" shows the largest deviations from the true positions and "RMS" shows RMS values of the differences between

measured and known positions. "Gävle" refers to Network RTK messages in static broadcast mode with Gävle as master station, "Leksand" refers to Network RTK messages in static broadcast mode with Leksand as master station, "Auto" refers to Network RTK messages in automatic mode with the closest SWEPOS station as master station and "VRS" refers to standard Virtual Reference Station solutions.

Table 4: Results in the vertical component.

	Mean deviation	Max deviation	RMS
Gävle	6 mm	74 mm	24 mm
Leksand[*]	3 mm	-75 mm	25 mm
Auto	2 mm	74 mm	22 mm
VRS	0 mm	85 mm	21 mm

[*]The values for "Leksand" are only based on measurements with the Trimble receiver.

Results from the test measurements concerning times to fixed ambiguity solutions with the four different methods are shown in Table 5. The measurement of the time to fixed ambiguity solution started when the rover was connected to the SWEPOS server, but before the correct mountpoint was chosen.

Table 5: Results concerning times to fixed ambiguity solutions.

	Mean value	Successful measurements
Gävle	38 s	98 %
Leksand[*]	42 s	99 %
Auto	38 s	99 %
VRS	25 s	99 %

[*]The values for "Leksand" are only based on measurements with the Trimble receiver.

CONCLUSSIONS FROM THE TEST MEASURE-MENTS WITH RTCM NETWORK RTK MESSAGES

The results showed that there are no obvious differences in accuracy regarding the measured positions between solutions with Network RTK messages and standard Virtual Reference Station solutions. Any noticeable difference between Network RTK messages in static (broadcast) mode and in automatic mode could neither be found. Concerning the distance to the master station for Network RTK messages in static broadcast mode, distances up to 160 km could be used without any noticeable degradation in accuracy.

Regarding the times to fixed ambiguity solutions, Network RTK messages showed slightly larger values than a standard Virtual Reference Station solution. A reason for this could be the size of the MAC network. A 14 station sub-net of the SWEPOS network was used for the test measurements (one master station and 13 auxiliary stations). In a smaller test that preceded the test measurements, a sub-net of only five SWEPOS stations was used. In the smaller test Network RTK messages in automatic mode was used and the mean value of the times to fixed ambiguity solutions was 24 seconds. This is practically the same value as was measured with standard Virtual Reference Station solutions in the larger sub-net. Another cause of the longer times to fixed ambiguity solutions for the Network RTK messages could be the 4-5 seconds latency of the geometric correction differences (msg 1016). The optimal size of the network for MAC messages is something that is suitable for further investigations.

Another thing was also noticeable concerning the longer times to fixed ambiguity solution, namely that the main part of the longest times occurred during a few days. The weather these days was characterized by weather fronts passing by with occasional showers. One conclusion could be that the amount of water vapor in the troposphere varied a lot these days and that the receivers had problems to model the effect of the tropospheric delay. Standard Virtual Reference Station solutions showed approximately the same times to fixed ambiguity solution on all days!

APPLICATIONS USING THE RTCM NETWORK RTK MESSAGES

RTCM Network RTK messages moves the computational burden from the Network RTK Server to the rover. Since the receivers/firmware used in this test must be considered to be of the first generation, the results are very good. There are clear indications that the accuracy in a large network using the Master-Auxiliary Concept will be rather homogeneous. The longer times to fixed ambiguity solutions are something that probably can be improved by polishing/tweaking the receiver firmware.

RTCM Network RTK messages can be used in the same way as the Virtual Reference Station solutions, but in order to be commonly used the MAC messages has to be extended to GLONASS as quickly as possible.

During the tests, there was also an attempt to move the receiver on a bicycle around 5 kilometres with fixed ambiguities in order to see if the Network RTK messages and receiver RTK engine in any sense supported the idea of seamless navigation. However Middle Swedish roads proved to be a too rough area for this kind of test. A test on a ship would be much better.

compare the performance of the SWEPOS Network RTK Service with and without GLONASS.

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