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Introduction and first applications of a Real-Time Precise Positioning Service using the Swiss Permanent Network 'AGNES'

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1 Introduction

The Swiss Federal Office of Topography has established the Automated GPS network for Switzerland (AGNES), which presently consists of 21 permanently operating GPS tracking stations. AGNES is a multipurpose network serving scientific applications (geodynamics and atmospheric research) as well as surveying applications (reference frame maintenance, densification of the reference frame). In addition, a positioning service is offered on a commercial basis under the product name *swipos*® (Swiss Positioning Service).

The paper concentrates on the high-precision real-time positioning service (accuracy 0.01-0.1m) using the GSM technique for broadcasting differential corrections (product name *swipos*-GIS/ GEO). Results of the first tests and applications will be presented in order to specify performance numbers.

2 SWIPOS-GIS/GEO positioning service

2.1 State of the AGNES network

The basic ideas of the permanent reference network AGNES were published in [*Gubler et al., 1998; Schneider et al., 1999*].

The AGNES network currently consisting of 21 permanent GPS stations is the backbone of the planned Swiss real-time positioning service *swipos*®. The installation of 8 additional stations should be realized by end of 2001. An overview of the network can be seen in [*Brockmann et al., 2001*]. The distance from any site to the nearest station is below 25-30 km with this network.

The infrastructure of AGNES (station equipment, communication lines, data download for postprocessing application using the internet, etc.) and the communication principles using GSM as broadcasting medium for the real-time positioning service was presented in the National Report 2000 [*Schneider et al., 2000*].

The real-time positioning service is based on a centralized concept. According to Fig. 1 the GPS data flow from the station computer (program GPSBase) via the federal network KOMBV ("named pipe" connection) to the monitor computer located at the Swiss Federal Office of Topography in Berne (program GPSMonitor). From there a winsock connection is established via the firewall to the communication computer (program GPSNet).

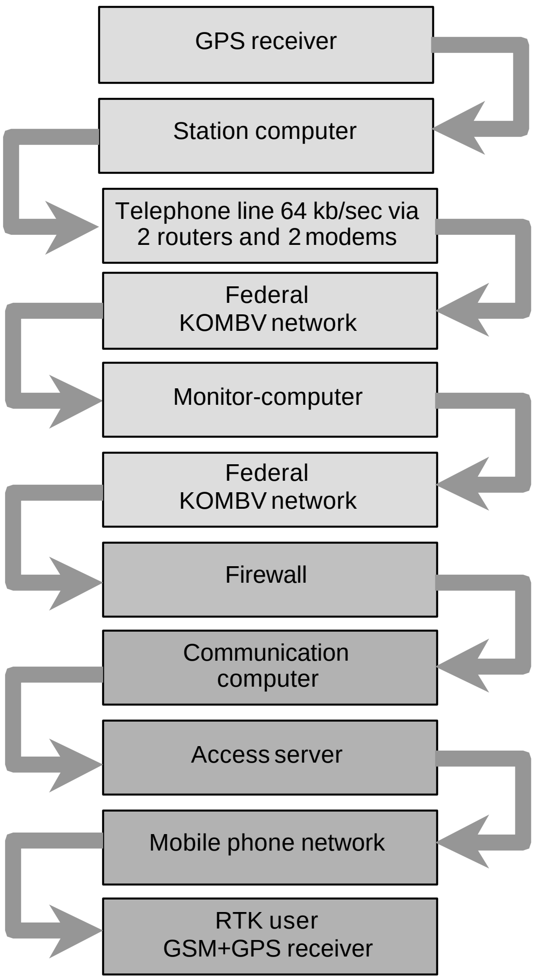

Fig. 1: Flow of GPS data from the reference receiver to the rover receiver

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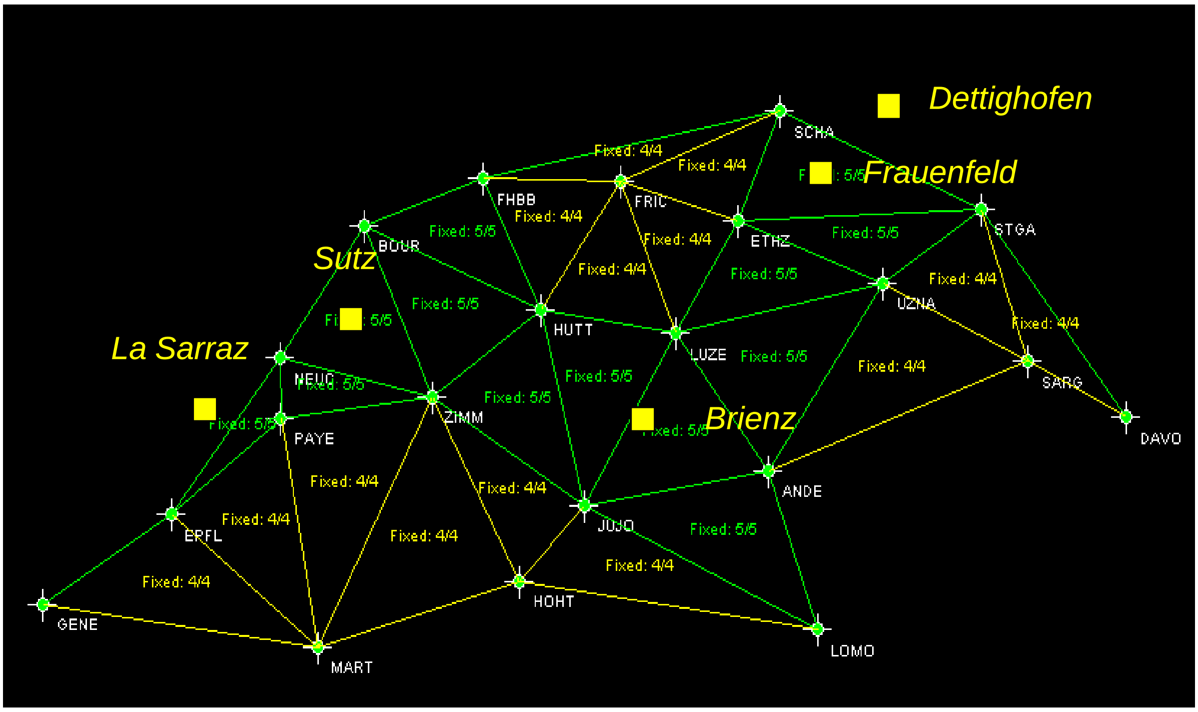

Fig. 2: Status of the AGNES RTK network. The sites Dettighofen, Frauenfeld, Brienz, Sutz and La Sarraz are used for performance tests.

The GPSNet software computes the network solution (including ionosphere, troposphere and ambiguity resolution) and prepares RTCM 2.2 corrections depending on the position of the user. The position is transmitted from the GPS receiver using GSM via the NMEA message (GGA string) to the communication computer.

The actual status of the network solution is displayed on the communication computer (Fig. 2). For computing a virtual reference station, the ambiguities in the triangles must be solved (indicated by green lines). If the ambiguities are not solved (red lines), or if only 4 ambiguities are solved (yellow lines), RTCM corrections of the next reference site are transmitted (RAW mode).

The access server (type Cisco AS5300) is able to handle 240 modems or 8 ISDN primary connections respectively. For the pilot service which has been in operation since March 2001, the single primary ISDN number handles 30 different users simultaneously.

2.2 Time delay of data transmission

In case a user is only a few kilometers away from an AGNES site, the data have to be transmitted several 100 km (depending on the distance to Berne) to finally reach the rover receiver.

The time delays between the GPS stations and the communication computer (all within the federal KOMBV network) are of the order of 30-100 msec (different sites may vary by up to 30 msec). The total time delay from the reference receiver to the rover receiver is displayed in Fig. 3. It is astonishing that the data transmission from the nearest site to Berne (data of ZIMM and all virtual reference corrections) shows the longest delay of up to 1.8 seconds.

In comparison, the time delays of a standard RTK method with a near-by reference station broadcasting corrections with a radio modem are approximately 0.6 seconds (see Fig. 3).

3 RTK tests and their results

First successful tests of the AGNES pilot network using the concept of "virtual reference stations" *[Wanninger, 1995; Wübbena et al., 1996]* were performed in May 2000. Some results of these tests were presented in the National Report 2000 *[Schneider et al., 2000].*

In the following chapters results from practical tests as well from tests designed to derive performance numbers of the positioning service are presented.

3.1 Densification Network Guggisberg

The Federal Office of Topography was asked by the surveying authority of the Canton of Berne to determine 73 second order points (LFP2) in the area Guggisberg (20 km southwest of Berne). It was the first practical test of the positioning service *swipos*-GIS/GEO. The communication infrastructure of *swipos* was used, but the virtual reference solution was not activated because the station density of the network was not yet sufficient in autumn 2000. Therefore, the RTCM corrections of the two nearest sites PAYE (20-30 km) and ZIMM (15-25 km) were used for the RTK measurements.

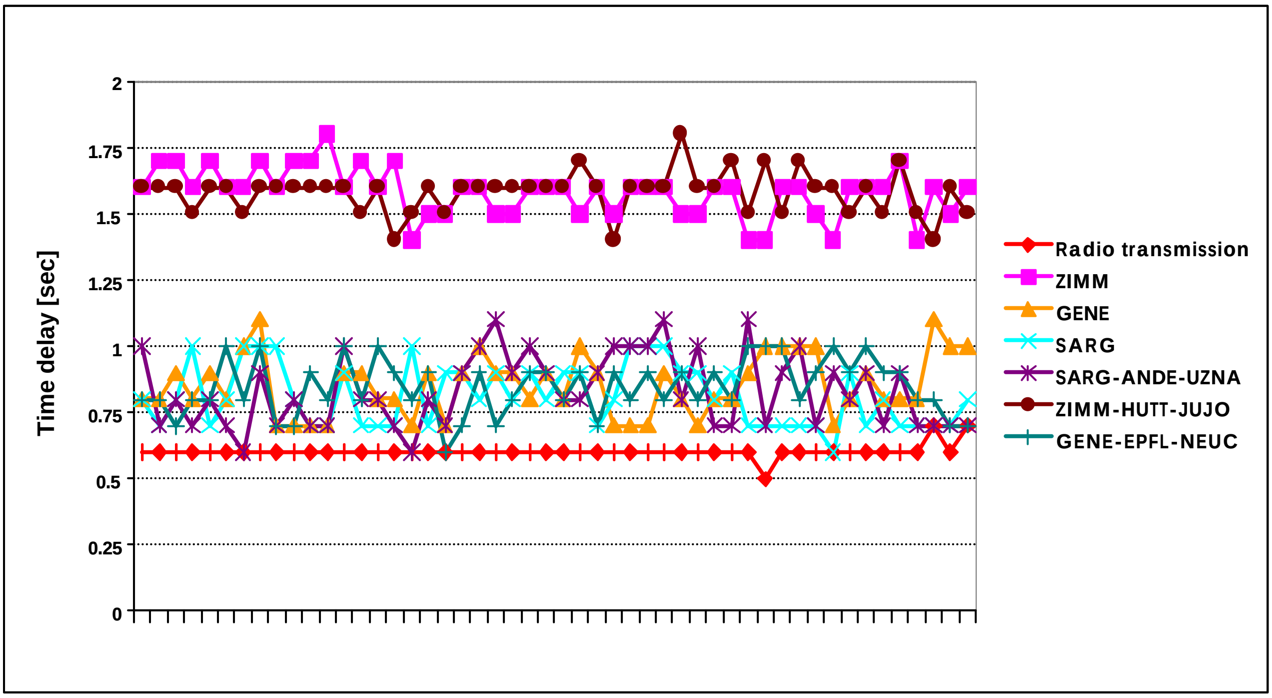

Fig. 3: Time delay of RTCM corrections for the sites ZIMM (5 km from Berne), GENE (125 km from Berne), and SARG (155 km from Berne) and RTCM corrections of network solutions from 3 different triangles compared to the radio transmission of a "standard" RTK application.

43 points were surveyed twice in the RTK mode, whereas 30 points were measured in the classical rapid static mode (20 min. measurements) with a local reference station in order to prove the precision of *swipos*-GIS/GEO (7 points). 23 further points were also observed in the rapid static mode because the GSM coverage was not sufficient.

19 points were used to integrate the measurements in the old classical tringulation network LV03, whereas 2 first order points and the 2 AGNES sites were used to integrate the network into the new reference frame LV95.

All RTK observations were carried out with the Leica SR530 system using an integrated GSM module for receiving the RTCM corrections. Trimble 4000 SSI receivers were used for the rapid static measurements.

In a common adjustment of all contributing coordinate estimates, a horizontal rms of 9.9 mm and a vertical rms of 23.4 mm (478 horizontal and 235 vertical components) were derived for the RTK coordinates.

In 80% of all cases the RTK results show horizontal residuals smaller than 25 mm and vertical residuals smaller than 40 mm.

3.2 Test network Avenches

In the scope of a diploma thesis of the "Ecole d'Ingénieurs du Canton de Vaud (EIVD)" a test network consisting of 9 points was established in the area of Avenches. The area covers 5x5 km and is located in the triangle of the AGNES permanent reference stations ZIMM, NEUC and PAYE. In order to test the virtual reference station concept, 4 sessions (with several initialization attempts) using the *swipos*-GIS/GEO service were measured with the Leica SR530 rover. In addition, initializations were carried out with correction data from the stations PAYE and NEUC only. A total of 180 coordinate estimates were used for the statistical analyses.

85% of the RTK coordinates showed horizontal differences smaller than 3 cm and vertical differences smaller than 4 cm.

In the case of the virtual reference concept, 100% of all horizontal differences and 90% of the vertical differences were below the mentioned tolerance level.

3.3 Performance test February 2001

The positioning service *swipos*-GIS/GEO has been operating with the status of a pilot service since March 2001. Systematic tests were carried out in February 2001 using the Leica SR530 rover. 5 sites (see Fig. 1) of the LV95 network were selected to test the following cases:

Case 1: Site inside a triangle (interpolation of a virtual reference station): Frauenfeld, Sutz

Case 2: Site outside a triangle (extrapolation of a virtual reference station): La Saraz, Dettighofen

Case 3: Site in a triangle with large height differences (JUJO reference station at 3600 m): Brienz

Case 4: Site far from the computer center located in Berne: Dettighofen

Several RTK test were performed on each site using the virtual reference station concept (VRS mode) as well as using only the nearest reference station (RAW mode). After each attempt a new initialization was forced by closing and reestablishing the GSM connection.

Almost irrespective of the mode (VRS / RAW) a precise coordinate result could be derived in less than 2 minutes (108 seconds in the average): 18 seconds for establishing the GSM connection, 13 seconds for starting the data flow, and 77 seconds for the initialization (ambiguity resolution).

The results of the statistical analysis for the 5 different test sites are shown in Tab. 1. The position / height error is the difference between the mean RTK coordinate estimate (derived from "# positions") and the well-known LV95 coordinates. The specified error quantity is the standard deviation and is an indicator of the RTK coordinate repeatability.

For both measurement types (VRS and RAW) the systematical differences of the RTK coordinates compared to the known LV95 coordinates are of the order of 2.0-3.0cm horizontally and 3.0-5.0cm vertically. The variations of each individual RTK solution with respect to the mean value is slightly smaller (1.0-2.0 cm horizontally, 2.0-3.0 cm vertically). Where the geometry was poor (GDOP values larger than 5) the coordinate estimates were excluded from the analysis because under these conditions the residuals may even reach the decimeter level for a coordinate component.

The initialization performance was not better for the virtual reference mode. This is due to the reduced number of satellites for which the network solution provides RTCM corrections. Observations with a low signal-to-noise (usually satellites with low elevation) are not used in the network solution. In some cases it may therefore happen that 7-8 satellites are visible to the rover, but correction data are only available for 5 satellites. Constellations of 5 satellites are usually critical for ambiguity resolution on the fly. For the next performance tests more satellites will be included in the network solution.

It should also be noted that the low performance in Dettighofen is mainly due to GSM communication problems in this area.

3.4 Conclusions

Based on the results of the three different tests presented here, the potential of the positioning service *swipos*-GIS/GEO could be proved. That includes the communication concept as well as the quality of the results. In many cases the RTCM corrections of the next reference station are suitable for a precise positioning service. The virtual reference station concept could not yet demonstrate any considerable gains, but improvements are on the way.

Since March 2001 a pilot service has been in operation. The service costs CHF 0.36 (€ 0.23) per minute (not including communication costs). For customers with special requirements (railroad, surveying authorities) solutions with a limited fee per year are available upon request.

	Virtual Reference Corrections (VRS mode)			Raw Corrections (RAW mode).		
Site (Test case)	# positions (success rate)	Position Error [cm]	Height Error [cm]	# positions (success rate)	Position Error [cm]	Height Error [cm]
Frauenfeld (case 1)	61 (88%)	3.0±2.3	4.6±3.8	- -	-	-
Dettighofen (case 2, 4)	12 (34%)	3.5±2.0	4.7±3.0	8 (73%)	3.1±1.7	1.8±0.9
Sutz (case 1)	5 (50%)	2.1±1.0	3.6±2.8	12 (92%)	1.6±1.3	5.3±3.4
Brienz (case 3)	16 (84%)	3.1±1.8	3.8±2.8	16 (80%)	3.3±2.3	2.7±2.2
La Sarraz (case 2)	3 (50%)	2.3±0.5	3.4±0.4	3 (100%)	1.1±0.7	4.0±0.6

Tab. 1: Results of the AGNES performance tests (February 2001).

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