Planning and realization of the Slovenian permanent GPS network

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1 Introduction

In 1999 the Surveying and Mapping Authority of the Republic of Slovenia (SMARS) started activities connected with the establishment of the first permanent GPS station in Slovenia. The project, »Establishment of permanent GPS station«, defined the technical, organizational and financial aspects of the establishment of the first permanent GPS station in Slovenia [1], which is located in Ljubljana. Soon after the termination of this project, the SMARS decided to continue activities and develop the national network of permanent GPS stations. This network was designed to cover the needs of many users from geodynamics to the cadastral and geodetic control and navigation. The permanent GPS network should be active one with the distribution of the carrier phase corrections, by either ‚VRS' (Virtual Reference Station) [2, 3], or the ‚FKP' (Flächen Korrektur Parameter) concept [4]. Whichever concept is to be chosen, a complete coverage of the national territory with the positioning accuracy at the (few) cm level is required. In addition, the network should be a ‚multipurpose' GPS network for public and private users), with subsequent possible densification at certain areas of interest. These goals could be achieved if the national permanent GPS network and GPS service, which would provide the maintenance and distribution of network data, are established simultaneously. GPS network and GPS service were at that time recognized as parts of vital importance for establishing a modern national geodetic infrastructure.

2 Functions of the permanent GPS network and GPS service

The fundamental function of a permanent GPS network and GPS service in Slovenia is the realization of a modern, high quality reference frame, which should be used as practical realization of a common European Spatial Reference System – ESRS, including horizontal (European Terrestrial Reference System – ETRS) and vertical (European Vertical Reference System – EVRS) components. Besides this fundamental task the network should serve as a reference for high precision GPS positioning in post processing and Real-Time Kinematic RTK-GPS mode for geodetic and other applications. In the long term operation the network should give us also the possibility to acquire the insight into the complex geodynamics of the area.

With such a network in operation, a broad usage of GNSS (Global Navigation Satellite System) positioning technologies in geodetic survey, geodynamics, navigation and GIS applications, is expected. Additional unforeseen uses will also come out, once such an infrastructure becomes available. Beside the national aspects, international aspects are equally important, such as participation within the existing and future European projects and networks, including the EUREF Permanent Network (EPN), European Combined Geodetic Network (ECGN), European Sea Level Service (ESEAS), etc.

Levels of positioning accuracy within the network are defined according to observables which are used for positioning:

- Differential GPS Service (DGPS Service), positioning accuracy within 0.5–1 m,
- Real-Time Kinematic GPS (RTK Service) 0.02–0.03 m

Both services are compatible with post processing and real time positioning. Data files for post processing are available via internet. Data for real time positioning are available in single reference station mode or in network mode (VRS, FKP). Higher levels of positioning accuracy could be obtained through rigorous post processing of data in regions of geodynamic interest (active tectonics, etc).

The GPS network and the appointed national GPS service together are shortly titled as SIGNAL (SI-Slovenia, G-Geodesy, NA-NAvigation, L-Location) which is owned and financed by SMARS, and organizational and technically operated by the Geodetic Institute of Slovenia. The national GPS service executes the tasks of an operational centre, a data centre and an analytical centre. The GPS service takes care of distribution of relevant information and necessary support to the users.

3 Aspects of the permanent GPS network planning

From the practical point of view, the final goal of the permanent GPS network realization is the availability of the RTK-GPS positioning within the entire national territory. Besides the general aspects of GPS site location selections to achieve this goal (obstacles, multipath error sources, etc.) few other aspects of site location in the network were considered.

One of the key aspects considered for selecting site locations were the locations of country's most densely populated areas. The potential number of users, availability of

necessary infrastructure (i.e. permanent internet link at the location) and good mobile phone (GSM, GPRS) signal coverage for the distribution of GPS data, all favour such locations. The biggest cities in the country are shown on Figure 4.
Another factor that was thoroughly considered is the physical stability of stations locations. Besides the local stability of the building where the GPS antenna is placed, and the ground beneath it, it is very important that the chosen location is not on or too near to a tectonic fault. The location of the main tectonic faults at the area, are also shown on Figure 4.
At the network planning considerable attention was devoted also to the definition of optimal geometry of the permanent GPS network.
At the time of network planning (1999) it was not very obvious that network RTK positioning mode will become a practically available positioning mode. At that time we were not sure that:

- appropriate data connections (ISDN, ADSL) between reference stations and data centre of GPS service will be available soon,
- mobile communications signal (GSM, GPRS, UMTS) will cover the considerable part of the country for the data distribution to the RTK users,
- quality commercial software for network RTK positioning will be available soon.

These were the reasons why both RTK positioning modes were considered: single reference station RTK and network RTK.
Single reference station RTK was at that time widely used for many cm-level applications. In this case positioning quality quickly degrades when user-to-station separation increases. To achieve cm accuracy users must operate within a radius of 20 km of the reference station. Beyond this limit, atmospheric biases degrade results [2]. Network RTK positioning enables high precision GPS positioning with the use of network of three or more reference stations to collect GPS data and extract information about the atmospheric and ephemeris errors affecting signals within the network. A central processing facility uses the reference stations data to generate corrections that are then relayed to RTK users operating within the region of network coverage [2]. Accuracy at the cm-level can be reached in the network RTK, where the separation of reference stations is from 30 to 70 km [3].

3.1 Definition of optimal network geometry for single reference station RTK mode

As it was mentioned, both types of positioning modes were considered: single reference station RTK and network RTK.
Obviously, the optimum number of necessary permanent stations for the single reference station RTK mode depends upon d_{1p} – the maximum acceptable distance between the user's receiver (rover) and the nearest reference station. It can be proved that among the planar regular networks of points, triangular lattice is the one with minimal number of points needed to satisfy that maximum distance criterion.

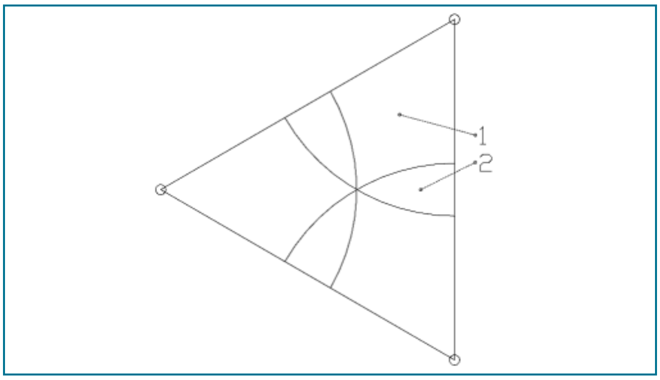

***Fig. 1:** Areas inside the network triangle where 1 or 2 permanent stations are to be found within radius of d_{1p}*

Relation between the maximum acceptable distance d_{1p} and the baseline length a (distance between two adjacent permanent stations) comes from the radius of the triangle's circumscribed circle (Figure 1):

$$d_{1p} = \frac{a}{\sqrt{3}} \tag{1}$$

The ratio between the area where only one permanent station is to be found p_{1p} (within radius d_{1p}) and the area of the whole network of triangles p_Δ is:

$$\frac{p_{1p}}{p_\Delta} = \frac{2 \cdot (9 - \pi \cdot \sqrt{3})}{9} \approx 0.791 \tag{2}$$

This means that about 79.1 % of the network area is covered with one permanent station within desired radius d_{1p}, the rest 20.9 % is also covered with a redundant station (two stations).

3.2 Definition of optimal network geometry for network RTK mode

The optimum number of necessary permanent stations for the network RTK approach depends upon d_{3p} – the maximum acceptable distance between reference stations. In other words: whichever is the position of the rover, there are at least three permanent stations within radius d_{3p}. It can be proved again, that among the planar regular networks of points, triangular lattice is the one with minimal number of points needed to satisfy that criterion. The maximum acceptable distance d_{3p} now is:

$$d_{3p} = a \tag{3}$$

Which means that d_{3p} is equal to the network baseline length a (distance between two adjacent permanent stations).

3.3 Consideration on required number of permanent stations

It can be analytically derived that minimum number n of permanent stations in a regular triangular network is estimated by:

$$n \geq 3 \cdot k^2 + 3 \cdot k + 1 \tag{4}$$

where k is:

$$k = \frac{\sqrt{2 \cdot p \cdot \sqrt{3}}}{3 \cdot a} \qquad (5)$$

p is the network area (the area within the convex hull around the stations) and a is the network baseline length. The equality in equation (4) can be reached in case of the regular triangular network of hexagonal shape. In that case, k is an integer number and represents type of the network, for instance elementary type ($k = 1$, $n = 7$), two-circuit type ($k = 2$, $n = 19$), three-circuit type ($k = 3$, $n = 37$), etc. (Figure 2).

3.4 Practical example: planning the Slovenian permanent GPS network

Using expressions (1) to (5), we obtain:

a) Single reference station RTK:
$p = 20251$ km^2 (area of the country)
$d_{1p} = 20$ km (radius within at least 1 permanent station is to be found)

$a = d_{1p} \cdot \sqrt{3} \approx 34.64$ km

$k = \frac{\sqrt{2 \cdot p \cdot \sqrt{3}}}{3 \cdot a} \approx 2.5487$

$n \geq 3 \cdot k^2 + 3 \cdot k + 1 \approx 28.13$

b) Network RTK:
$p = 20251$ km^2 (area of the country)
$d_{3p} = 60$ km (radius where at least 3 permanent stations are to be found)

$a = d_{3p} = 60$ km (value between 30 and 70 km, chosen according to country dimensions)

$k = \frac{\sqrt{2 \cdot p \cdot \sqrt{3}}}{3 \cdot a} \approx 1.4715$

$n \geq 3 \cdot k^2 + 3 \cdot k + 1 \approx 11.91$

In the case of ideally and convex shaped area of the country, the estimated number of stations for the single reference station RTK mode would be at least 29 and for the network RTK mode at least 12.
The idea of national GPS network, consisted of 29 reference stations, was not accepted, mainly due to the funds available. This is why we focused our further activities into the establishment of permanent GPS network to operate in network RTK mode.
The initial stage of the optimal network geometry planning was to take the ideal network ($a = 60$ km) and fit it to the shape of the country (Figure 3). Because of the irregular shape of the country and taking into account other aspects of network planning, such as locating the network reference stations in urban areas (users, data infrastructure) and away from the main tectonic faults, we found out that the network of 15 permanent stations could satisfy most of above criteria (Figure 4). The finally defined positions for permanent reference stations are shown on Figure 5. Geometric characteristics of the network are: the average distance between adjoining reference stations is 49.5 km, the minimal distance is 24.1 km and the maximal distance 73.8 km.

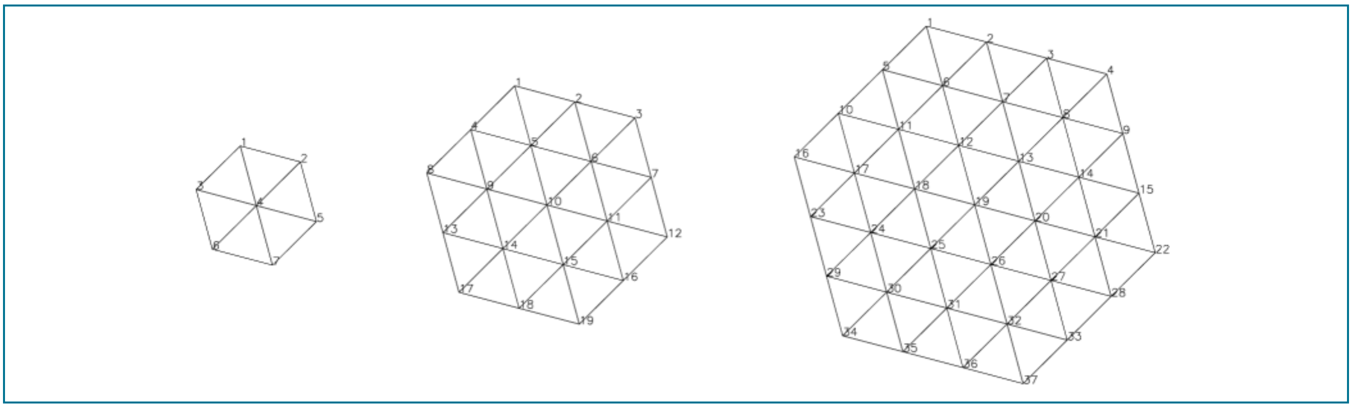

Fig. 2: Regular triangular networks of hexagonal shape: the elementary network (left), two-circuit network (middle), and three-circuit network (right)

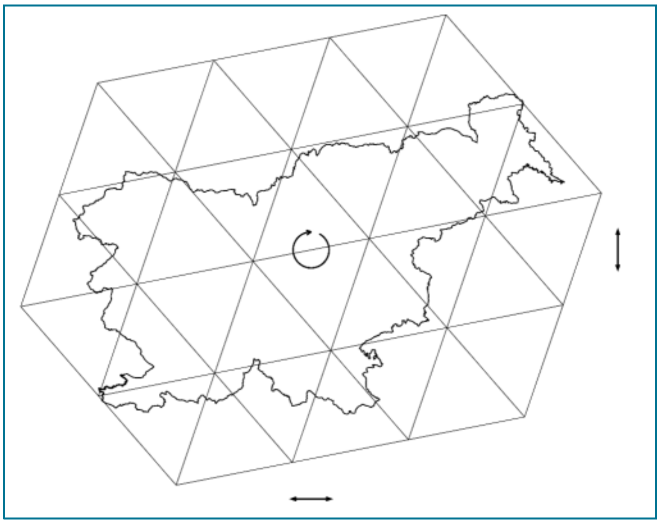

Fig. 3: The initial stage of the station locations selecting

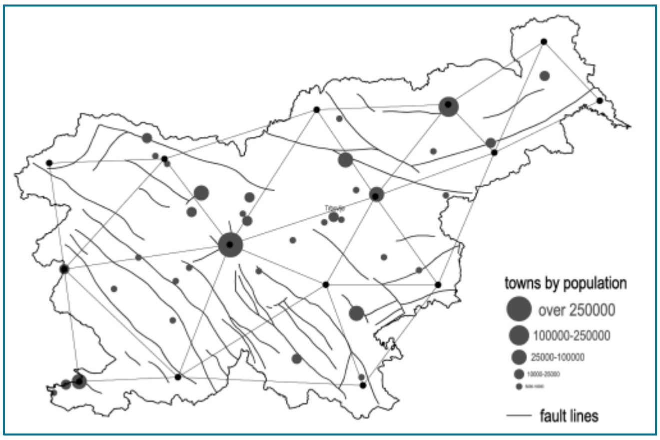

Fig. 4: Final site locations of the national permanent GPS network in accordance with geometric, tectonic, infrastructure, and other aspects. Note that triangles are only provisionally drawn and do not adhere to those formed by ‚VRS' or ‚FKP' networking software

4 Current status and data management in the national GPS network

From June 2006, all fifteen permanent stations are available to the users, therefore a full coverage of the national territory has been achieved (Figure 5). Currently, the station Ljubljana is part of EPN, and the station Koper is a part of ESEAS, as it is collocated with a national tide gauge station. Additionally, SIGNAL and APOS (A – Austrian, PO – Positioning, S – System) mutually exchange data from five stations close to the state border from each country. A private Croatian station in Zagreb is also temporarily included in SIGNAL network.

Observation data from reference stations is analysed, processed, stored and distributed by the national GPS service. The service has acquired a software package for the national GPS reference station network. The installed software GPSNet by Trimble-Terrasat manages the following functions: receiving raw data from permanent receivers, processing data in a network module (VRS or FKP), storing data and distributing processed data to users.

4.1 Data transfer from reference stations to the control centre

Data from all reference stations is continuously transferred to the central workstation at the centre. The observation data is transferred in raw format through VPN (Virtual Private Network) tunnel and permanent ADSL internet connection. The GPS receivers at the reference stations are directly connected to the internet modem therefore no computer between the receiver and the modem is needed. The central workstation is permanently connected to the internet via LAN (Local Area Network).

4.2 Data processing in the centre

The network software receiving raw data from the reference stations must handle raw data formats from different receiver manufacturers. Data management is centralized, which holds many benefits compared to managing data separately at each station. It offers more control over the network, it is more economic and it's the only possible configuration to take full advantage of the network RTK approach. The network software handles the reception of raw data from all permanent stations simultaneously, remote monitoring of the stations, performs real time network analysis and network RTK solutions, creating standard RTCM messages for real time use and conversion and storage of RINEX files for post processing. In addition, a web-server for real time distribution is also included in the package.

4.3 Distribution of processed data to the users

The processed data from the centre is distributed to the field users in real time and is available on the internet for post processing. Real time distribution could be established by radio-modems or via the existing mobile phone network (GSM). However, full coverage of the radio sig-

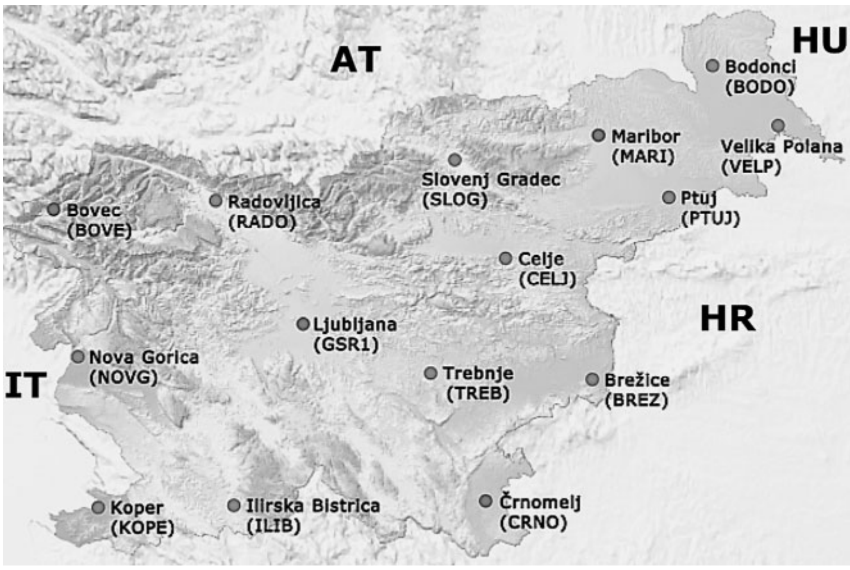

Fig. 5: Final realization of the national permanent GPS network

nal is not realizable, therefore an existing GSM network is a reasonable solution. In this case the GPS service has no expenses to bear for building and maintaining a distribution network, and the coverage is almost complete as far as urban areas are concerned. It also offers the users some choice of which mobile operator to use.

Data for real time surveys is distributed in the standard RTCM-104 format. Field users receive RTCM data via built-in GSM modem or standalone GSM phone. The connection can be established through mobile internet with a data call CSD (Circuit Switched Data) or data connection, such as GPRS (General Packet Radio Service), EDGE (Enhanced Data Rates for GSM Evolution), UMTS (Universal Mobile Telecommunications System) or WLAN (Wireless Local Area Network). The main difference between the CSD and data connection is the charge rate. The CSD is charged by the amount of on-line time and data connection charge depends on the amount of transferred data. Each user can choose the optimal option for his needs.

The connection can also be established with a CSD call to the GSM-Server of the national mobile service provider, or directly to a GSM modem in the centre. In the first case, the GSM-Server consists of multiple ports, each with its own number and a source, which can be RTK single station, VRS or DGPS. Each port enables multiple simultaneous connections. The second option allows only one user per modem at the same time. It is rarely used.

Users using mobile internet receive the desired data from the centre via NTRIP (Networked Transport of RTCM via Internet Protocol). Modern GPS instruments have the NTRIP included in their field software. Those who don't own such instruments can use a pocket PC and install the NTRIP client, which is freeware. The user enters broadcaster's IP, user name and password, which is acquire from the GPS Service. After logging on, the user selects the desired mount point from the source table. At the time the user logging on to Slovenian GPS network, can receive RTK data from individual GPS stations in RTCM 2.3, DGPS data from selected stations in RTCM 2.1, VRS data in RTCM 2.3 or VRS data in RTCM 3.0 format. VRS (Virtual Reference Station) is computed by the managing software in the GPS centre from all the available data in the network. The approximate position of the user's rover is required for VRS computation. Therefore the user must send the current location in form of NMEA message to the network centre. After generating virtual data for the user's position the software distributes the data to the user.

RINEX data for post processing is available on the internet through the web application. The users log on to the site, select the desired network station, date, time and interval of the base data. Users can download RINEX or Hatanaka compressed RINEX files. After the most recent addition to the software, the users also have option to download VRS for post processing in RINEX format.

5 Conclusion

The SIGNAL network was under construction for last five years. After a period of hesitation, surveyors have adopted it as an unavoidable means of amendment of official topographic and real estate data. The number of registered users is approaching 200, which is quite satisfying for a country of 2 million inhabitants. Two specific fact have crucially contributed to increase the interest in SIGNAL:

- The SMARS' „Strategy of Transition to a New European Coordinate System" was accepted by national government in 2005.
- By virtue of the new „Law on Recording of Real Estate Data" each update of coordinates in land cadastre undertaken from 1.1.2008 on, must be registered in new national reference system.

Although GPS survey still has some drawbacks in everyday practice, especially in urban and forested or otherwise obstructive situations where one needs to combine it with classical terrestrial measurements. But now the national network of permanent GPS stations plays the fundamental role in the modernization of geodetic survey, geodynamic monitoring, navigation, and, generally, in a transition to cross-border global geo-referencing.

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Abstract

In the article we present planning and realization of a multipurpose national permanent GPS network in Slovenia. In the planning phase we searched for the optimal spatial distribution of the permanent GPS stations in the network according to several different criteria. We also present the functionality, operation, management, data distribution and final status of the national permanent GPS network.

Zusammenfassung

Das permanente GPS-Netz Sloweniens wird vorgestellt. Zur Festlegung der optimalen Positionen der Stationen werden verschiedene Kriterien berücksichtigt. Die Funktionalität, die Unterhaltung und die Datenübertragung beim praktischen Einsatz des permanenten GPS-Netzes werden untersucht und beurteilt.