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Determining the Position of GNSS Network Stations based on the Permanent European GNSS EUREF Network (EPN)

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Abstract: ***Nowadays technological development in the field of Geodesy, as in any other field, has made a radical change. This has led to the creation of new opportunities to further extend the science of geodesy. The creation of the GNSS satellite system has brought a revolution in the methodology of determining the position of different objects in nature, as the methods used in this case are completely different from classical positioning methods. Today the GNSS system can be called a consolidated system, having been used and performed for several decades. With the growth of communication technology and its integration with the GNSS system, positioning (at cm level) is performed in real time. In the measurement process, getting good and consistent accuracy will always be a big challenge. For this reason, there is always a need to create methodology to increase this accuracy and make it stable throughout the measurement territory. The construction of geodetic networks enables us to create a network of known stations (points) covering a designated territory where any measurement based on these known stations will be obtained within the accuracy of the built network. In this article we will show the creation of a geodetic network using the GNSS satellite positioning method. The built network will be a network based on the permanent European GNSS EUREF network (EPN). To determine the position of points in our network, we have followed several stages that begin with the GNSS measurement process, post-processing of baselines for every measured point by connecting to EPN stations and end with the adjustment computations of our network stations. After the completion of these stages, we will determine the final position of network stations which can be used later to support various measurements that can be realized in the created network area.***

Keywords: GNSS, EPN, EUREF, Geodetic Network, GNSS Network Adjustment, Baseline post-processing

1. Introduction

The EUREF Permanent Network (EPN) is a network of permanent GNSS stations that were created in 1995 with the main aim of supporting and improving the maintenance of the European Terrestrial Reference System (ETRS89) and its successive realizations (Adam) etc. 2002). EPN is operated under the umbrella of EUREF, IAG (Inter-National Association of Geodesy) sub-commission for Europe, integrated into sub-commission IAG 1.3, Regional Reference Frameworks.

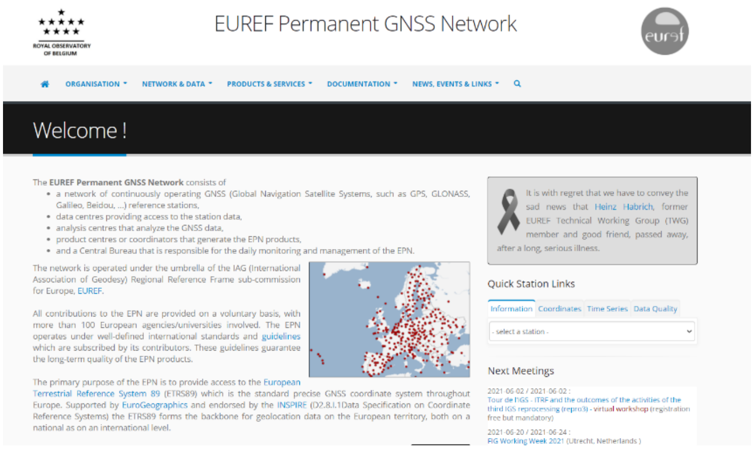

Figure 1: EUREF Permanent GNSS Network (EPN) website

Like the GNSS International Service (IGS); (Johnston etc. 2017), EPN is based on voluntary contributions. More than 130 agencies all over Europe contribute to the EPN. EPN stations upload data to EPN (DC) data centres, which permanently archive data and make it freely available to all users.

RINEX data from EPN stations is available for free through the FTP from the centres of two regions located in the Bundesamtfür Kartographie und Geodäsie (BKG, Germany) and BundesamtfürEich- und Vermessungswesen (BEV, Austria), and a historical data centre, managed by the Central EPN Bureau. Both regional data centres store hourly and daily data in The RINEX 2 and RINEX 3 formats. The historical data centre only preserves daily RINEX files and homogenizes their title for files to be in agreement with station data as provided in the station's page writings. EPN CB constantly scans both regional EPN data centers, and scanned results become available on the EPN CB website through interactive settings.

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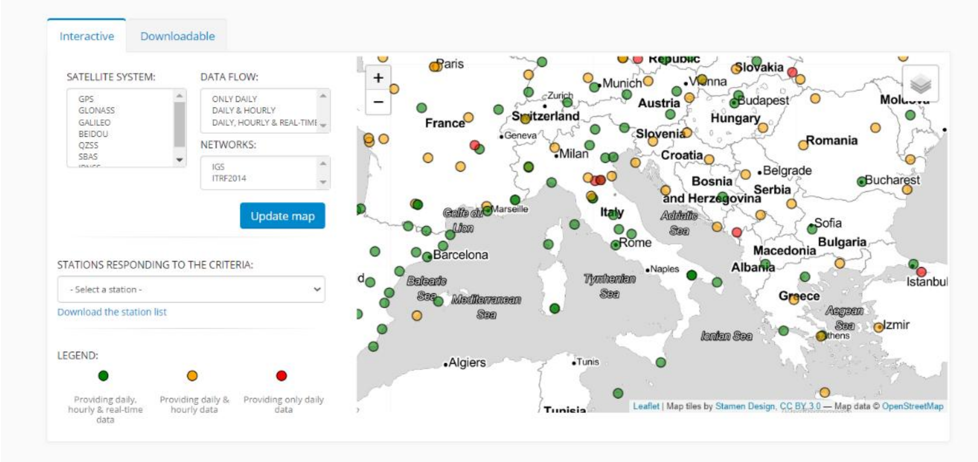

Figure 2: Interactive map of EPN stations

The interactive environment enables information on EPN network stations to be viewed, as well as detailed information on these stations can be obtained. The services offered can be summarized as:

- The possibility of identifying the Station by navigating through his metadata.
- The possibility of downloading measurements in the RINEX format to one of the network-related centres (BKG or BEV) through the FTP service.
- The possibility of taking the position and velocity of moving stations in a certain epoch.
- The possibility of obtaining information on the quality of data in the RINEX format.

Implementation of the GNSS network

Study area

The area in which the construction of the GNSS network was carried out covers the surface of the city of Tirana. For our network it was decided to determine 3 stations, respectively at 3 ends of the city of Tirana:

- Station 1 – near Lake of Tirana
- Station 2 – near the former kinostudio area
- Station 3 – near The Tirana-Durres Highway behind the Casa Italia trading center.

The stations location were defined in open places and in visible positions. The benchmarks of the stations were materialized on the field in order to carry out the measurement process.

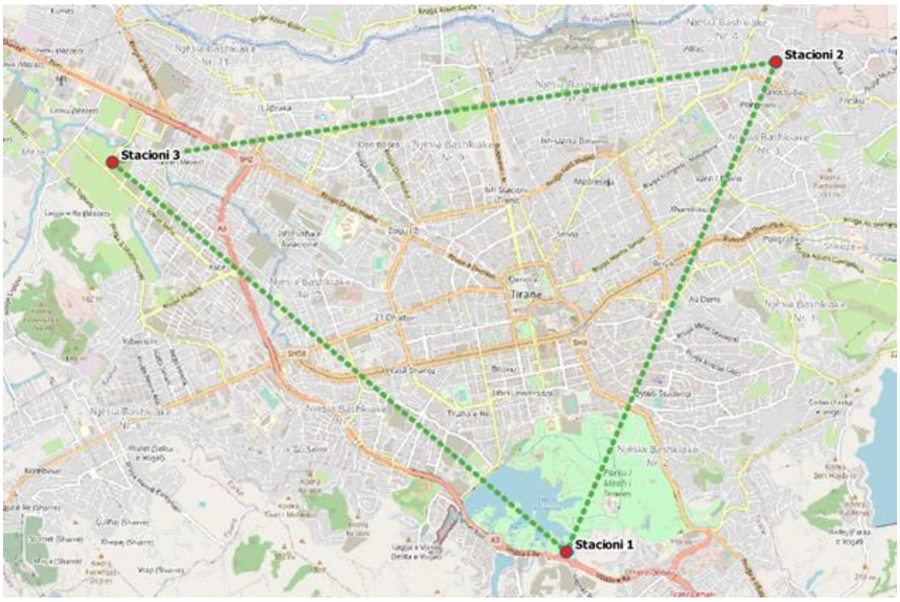

Figure 3: Position of the local GNSS network

Measurement process

In our case study, we decided that measurements would be carried out at the same time at the 3 Stations. This is because during network compensation in addition to baseline measurements carried out through our network stations and EPN stations we could have as excess measurements and the baselines of our network. Initially at each of the stations, their position on the ground was permanently marked, and then GNSS receivers were positioned for measurement.

Figure 4: Station 1

Figure 5: Station 2

Figure 6: Station 3

The initialization of GNSS receivers was then carried out so that they could begin with the measurement process. Measurements were carried out in the period from 2021/05/08 08:51:38 (GPST) to 2021/05/08 12:55:24 (GPST). After the measurement process, from GNSSreceiverswe collected the measurement session for each of the stations in the RINEX Format.

Reference stations and additional data to be used inprocessing.

Our network stations will rely on the permanent ETRF (EPN) network. The baseline post-processing will be carried out through 2 EPN stations respectively **USAL00ITA** (Lecce, ITA) and **DGOR00MNE**(Podgorica, MNE). From the FTP service enabled by BKG, Germany we received the daily RINEX data for these two stations. This was done by going to the https://www.epncb.oma.be/ page from where we can downloadthe RINEX data.

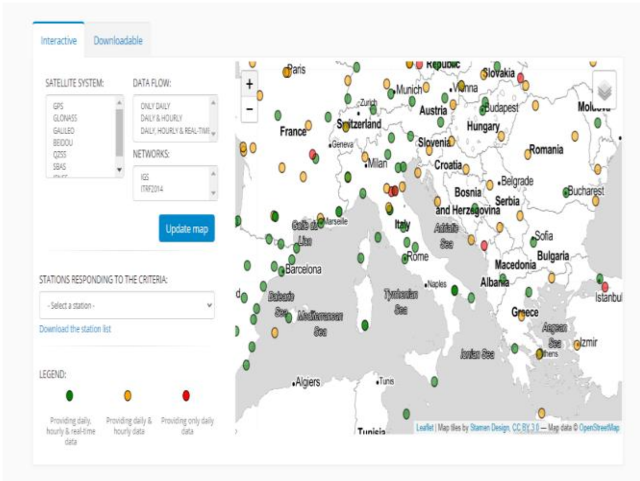

Figure 7: Interactive map of EPN stations

Using the interactive map environment enabled on the EPN portal we can access information for each station.

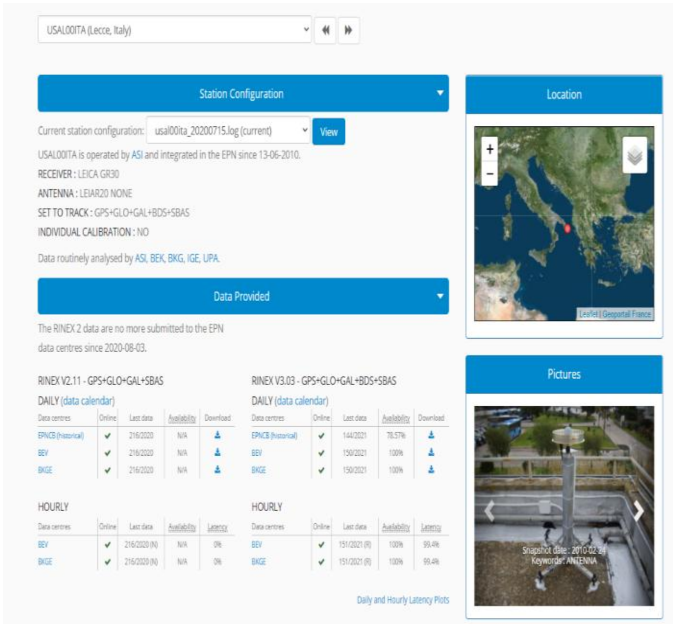

Figure 8: Interactive environment for the EPN station

Detailed information can be obtained on each of the EPN stations:

- Station identification navigating through its metadata.
- FTP service on daily measurements in the RINEX format in one of the network-related centers (BKG or BEV).

- Position and velocity of movement for the stations in a certain epoch.
- The quality of the data in the RINEX format.

At the "Data Provided" environment, we are given the possibility to access the EPN station measurement calendar.

Through the calendar we can download RINEX data for measurements carried out by EPN stations on the day we are interested. In our case, measurements for the network stations were carried out during GPS week 2156 on day 128/2021 (08.05.2021).

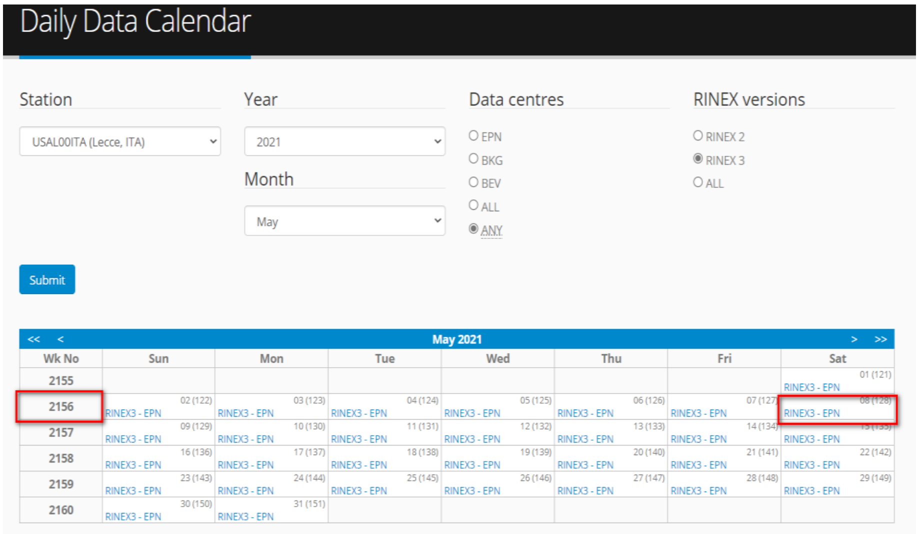

Figure 9: EPN station measurement calendar

For each of the EPN stations where our Network will be referenced, we downloaded The RINEX data on the date we carried out measurements for the construction of this network. RINEX data from EPN stations contain daily measurements of these stations with a frequency of 30 seconds for each measurement.

The baselines that will be post-processed have a considerable length that exceed 100km. For this reason, it is necessary to take into account the impacts of errors that come as a result of satellite orbits, Earth rotation parameters, satellite hours, the impact of the ionosphere layer, the impact of the troposphere layer, etc.

For this reason, before processing measurements, we should also provide the data that will be used in the post-processing of network baselines.

The additional data used for calculating baselines:

- Precise satellite orbits
- Earth's rotation parameters
- Satellite clocks
- Global map of the ionosphere

These data are released by authorities overseeing global positioning systems services and published at a day-to-day level. The above data will be taken from NASA's Space Geodesy Data Archive. High-accuracy calculations for this data are published approximately 13-14 days from the date of the performed measurements. In the case of our network, measurements were carried out on 8.05.2021 but the final accurate data we managed to obtain on 22.05.2021. The exact final additional data will have as a prefix in their name respectively:

- **igsWWWWD.sp3** (Precise satellite Orbits)
- **igsWWWWD.erp** (Earth Rotation Parameters)
- **igsWWWWD.clk** (Satellite clocks)
- **igsDDD.21i** (Global Map of the Ionosphere)

Where:

- WWWW shows GPS week where measurements are carried out (in our case week 2156) and D shows the number of the day of the week (from 0 for Sunday to 6 for Saturday day)
- DDD in the case of the global map of the ionosphere shows the number of the day for 2021 (in concrete case day 128).

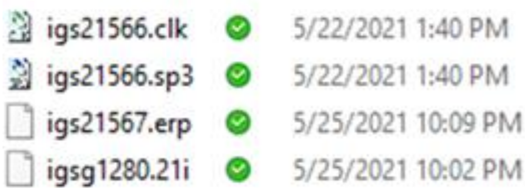

Figure 10: Additional data

After collecting RINEX data for EPN stations as well as the additional data, we are ready to continue the post-processing of the baselines for our network.

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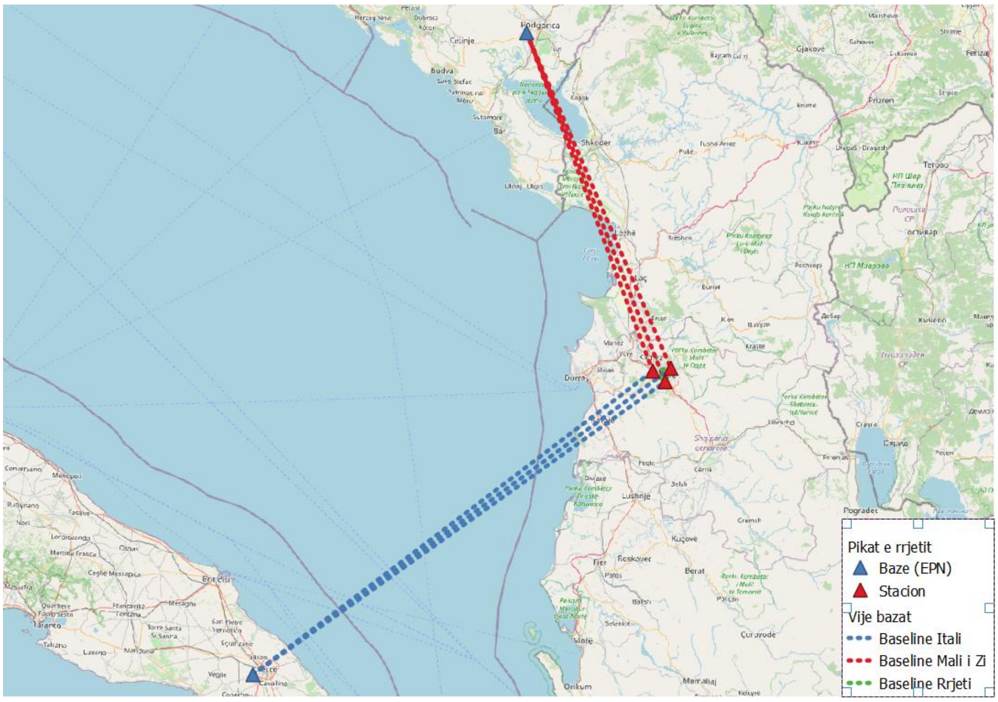

Figure 11: Baseline visualization of our use case network

Conversion of EPN station coordinates at the epoch of our GNSS measurements.

In order to realize the conversion of coordinates in the epoch of our measurements, respectively the epoch$t$ = *128/2021*, ETRF2000reference, coordinates and velocities of EPN stations must be collected in the ETRF2000reference for the epoch t_0 = *001/2010*.This data is periodically published by the EUREF Permanent Network service.

EPN_A_ETRF2000_C2145.SSC

ETRF2000	epoch t_0	Position (m)			Velocity (m/y)		
		X	Y	Z	V_X	V_Y	V_Z
316/2017 - 051/2021	001/2010	4627542.214 ± 0.001	1513540.712 ± 0.001	4106448.055 ± 0.001	-0.0032 ± 0.0001	-0.0002 ± 0.0001	0.0021 ± 0.0001

ETRF2000	epoch t_0	Position (m)			Velocity (m/y)		
		X	Y	Z	V_X	V_Y	V_Z
349/2019 - 051/2021	218/2020	4453507.152 ± 0.001	1551168.228 ± 0.001	4280016.168 ± 0.001	NA	NA	NA

Figure 12: Coordinates and Velocity Vectors published by EUREF

The coordinates of the EPN stations to be entered into the calculation of baselines will be the coordinates that will be convertedat the 128/2021 epoch (2021.35). The calculation of coordinates in the epoch t=2021.35 will be carried out according to the following formulas:

$$X(t) = X(t_0) + (t - t_0) V_X;$$
$$Y(t) = Y(t_0) + (t - t_0) V_Y;$$
$$Z(t) = Z(t_0) + (t - t_0) V_Z;$$

For each of the Stations we will receive X (2021.35), Y (2021.35), Z (2021.35), these coordinates will be used as initial data for post-processing our baselines.

Table 1: Coordinates of EPN stations in 2021.35 epoch

Base	X	Y	Z
A (Italy)	4627542.1880	1513540.7100	4106448.0760
B (Montenegro)	4453507.1600	1551168.2310	4280016.1700

Post-Processing of measured baselines

Post-processing of baselines is a process that enables the correction of errors that occur during GNSS measurements such as: Corrections for "Multi-path", Corrections for the Ionosphere, Corrections of The Geometry of Satellites, etc. The post-processing was carried out by RTKLib Software which enables the calculation of baselines by accepting all additional data/parameters such as: Precise satellite orbits, Earth rotation parameters, satellite clocks, Global map of the ionosphere. Below we are showing the results of the baseline post-processing outputs from the RTKLib software:

Table 2: Baseline post-processing output

Baseline		ΔX	ΔY	ΔZ	S_{xx}	S_{xy}	S_{xz}	S_{yy}	S_{yz}	S_{zz}
Start	End									
A	1	-113498.5261	113721.0947	81617.3963	5.00E-04	3.00E-04	3.00E-04	4.00E-04	2.90E-04	6.00E-04
A	2	-117137.3664	114512.8065	85235.2527	6.20E-04	3.00E-04	3.50E-04	3.70E-04	2.70E-04	5.60E-04
A	3	-114334.5047	108659.9868	84389.2870	6.00E-04	3.00E-04	3.00E-04	4.00E-04	3.00E-04	6.00E-04
B	1	60536.4278	76093.6371	-91950.5832	7.40E-04	3.70E-04	5.00E-04	4.40E-04	2.80E-04	7.40E-04
B	2	56897.6783	76885.3093	-88332.7211	7.80E-04	4.40E-04	4.90E-04	4.90E-04	3.60E-04	6.70E-04
B	3	59700.4335	71032.5333	-89178.6595	7.30E-04	3.90E-04	4.90E-04	4.60E-04	3.00E-04	6.60E-04
1	3	-835.9800	-5061.0972	2771.9076	4.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	3.00E-04
2	1	3638.7426	-791.6604	-3617.8595	3.40E-04	1.90E-04	2.30E-04	2.00E-04	1.60E-04	3.10E-04
2	3	2802.7602	-5852.7678	-845.9497	3.50E-04	2.00E-04	2.40E-04	2.10E-04	1.70E-04	3.30E-04

Adjustment Computations on the GNSS network

One of the methods used to adjust for GNSS networks is the adjustment of measured baselines vectors between the stations of a geodetic network. A baseline is measured using the static positioning method, where two GPS receivers are placed at the two stations of the baseline, respectively. Usually, one of the stations can be a known or measured point for a relatively long time. Before carrying out the adjustment process of a GNSS network where the respective baselines between the network stations have been measured, the post-processing of the measured baseline must be performed in advance for each of the baselines. After post-processing of the baseline A-B, where point A is a known point, the corrected vector AB will be obtained. Calculated ΔX, ΔY and ΔZ will be obtained, respectively. Simultaneously from the post-processing report will be obtained also the square residuals for σx, σy, σz. Since the baseline vectors in the network are measured independently the square residuals for ΔX, ΔY and ΔZ will be different for each baseline.

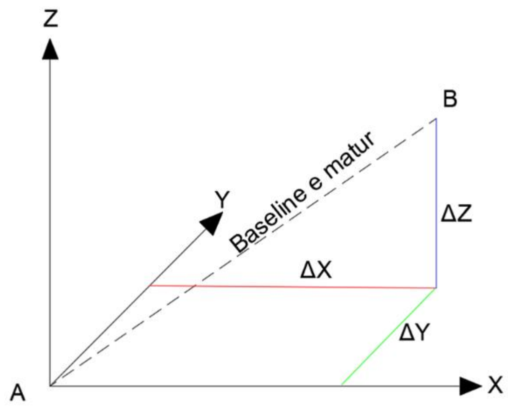

Figure 13: Display of the baseline vector

Adjustment of network baselines

In our case to determine the coordinates of points 1, 2 and 3 for the GNSS network, based on the figure of the network shown schematically, we have to measure thebaselines A-1, A-2, A-3 as well as B-1, B-2, B-3.Fromthe post-processing of the measuredbaselines, we willobtain the vectors ofthese baselines expressed with the differences of the coordinates ΔX, ΔY and ΔZ.Since the baselines are measured independently the coordinates of the same point, measured from two different baselines will have different corrections, for example: the coordinates of point 1 calculated from the differences processed frombaseline A-1 will be different from the coordinates calculated from the differences processed frombaseline B-1.

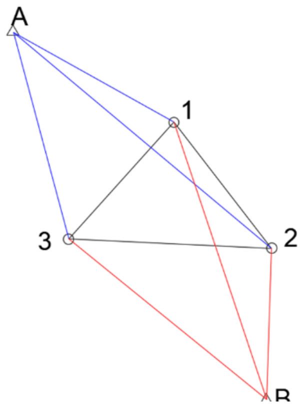

Figure 14: Schematic representation of the baseline measurements for the use case network

Network adjustment should be carried out in such a waythat corrections should be distributed proportionally to each of the network stations. The error equation will be like this:

$$X_1 - X_A = \Delta X_{A-1} + v_{X_{A-1}}$$

$$Y_1 - Y_A = \Delta Y_{A-1} + v_{Y_{A-1}}$$

$$Z_1 - Z_A = \Delta Z_{A-1} + v_{Z_{A-1}}$$

For everybaseline, three equations willbe obtained. The equations will be laid for all the measured baselines. In this case 18 equations will be formed. In matrix form the error equations will be:

$$W \cdot A \cdot X = W \cdot L + W \cdot V$$

Where: W is the matrix of measured baseline weights. This matrix is obtained from the inverse of the weight coefficient matrix calculated for the measured baseline. It is a square matrix (3x3):

$$\Sigma = \begin{bmatrix} Sxx & Sxy & Sxz \\ Syx & Syy & Syz \\ Szx & Szy & Szz \end{bmatrix}$$

$$W = \Sigma^{-1}$$

Based on the least squared theory [WVV] = min, we move on to the solution of the normal system where we find the adjusted coordinates for the network stations.

$$X = N^{-1} \cdot A^T \cdot W \cdot L$$

Where: Vector X will give usthe coordinates of our GNSS network stations.

Network adjustment results

Using the adjustment methodexplained above we willobtain the results for the position of stations.

Table 3: Adjusted Coordinates of the stations

Station	X	Y	Z	Sx	Sy	Sz
1	4,514,043.613	1,627,261.849	4,188,065.542	0.0368	0.0296	0.0362
2	4,510,404.856	1,628,053.516	4,191,683.394	0.0378	0.0299	0.0364
3	4,513,207.625	1,622,200.747	4,190,837.450	0.0377	0.0298	0.0361

2. Conclusions

In this article we have shown how to implement a GNSS Geodetic Network by referencing it to the European Permanent GNSS Network EUREF. We have followed several stages that begin with the GNSS measurement process, post-processing of baselines for every measured point by connecting to EPN stations and end with the adjustment computations of our network stations. We have shown that to obtain the coordinates for the stations of a geodetic network there are different stages that must be followed. Adjustment computations of the GNSS Network is needed to obtain the adjusted coordinates of the stations. Using the method described above we obtained adjusted coordinates with square residuals around 3.5 cm. With these results, we can conclude that this method can be used for different topographic works like defining the volumes for an excavation site or for surveying purposes for cadastral measurement.

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