

Single-Frequency Receivers as Permanent Stations in GNSS Networks: Precision and Accuracy of Positioning in Mixed Networks

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Abstract Continuous Operating Reference Stations (CORSs) are widely used for many purposes including precise positioning, mapping and monitoring. These architectures are composed of a control centre and a number of permanent stations consisting of geodetic antennas and dual frequency receivers. This infrastructure is costly due to the instruments used and has the additional disadvantage in that inter-station distances between CORSs, that are often too high if a single-frequency receiver acts as a rover. This study focuses on the usefulness of permanent single-frequency stations in order to increase density of existing CORSs for monitoring purposes. In this connection, some innovative GNSS networks composed of geodetic and mass-market L1 receivers have been developed and tested, analyzing the performance of rover positioning in terms of quality, accuracy and reliability in real time. Some tests have been carried out considering different types of receivers (geodetic and mass market) and antennas (patch and geodetic), in real-time mode. The results obtained show that with a “classical” network (where the mean inter-station distances between CORSs are about 40 km) an accuracy of about 5 cm can be achieved after fixing the phase ambiguity with a mass-market L1 receiver acting as rover. In addition, the Time-To-Fix period is very short, being less than 2 min. Despite the obvious fact that increased inter-station distance leads to reduced accuracy, the degree of precision obtainable remains useful for many applications, such as mobile mapping and traffic control. In short, the experiments under examination performed with low-cost GNSS receivers will be useful for many types of applications (landslide monitoring, traffic control), especially where the inter-station distances of permanent GNSS stations are around 40 km.

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1 Introduction

Use of GPS/GNSS instruments is today common around the world, both at a commercial level and for academic research. Over the last ten years, CORS networks have been created specifically to achieve the goal of extending classical RTK (real time kinematic) positioning over an area of more than 40 km. Several experiments were made in the past to evaluate the maximum precision obtainable in a CORS network when using either geodetic or mass-market GNSS receivers. With these types of instruments it is possible to achieve accuracies of a few centimeters and a few millimeters in ‘Real time’ (Bellone et al. 2016) and post-processing (Dabove and Manzano 2014) approaches respectively.

This work takes its starting point from the research described above, in particular focusing on the usefulness of single-frequency multi-constellation GNSS mass-market receivers in NRTK networks as rovers, and also on the use of these kinds of instruments as permanent stations serving to densify existing CORSs, particularly for monitoring purposes. Two different types of CORS network are considered in this paper in terms of real-time positioning: the first is the “small” network and the second is the “large” one, where the mean inter-station distances are about 25/30 (Sass 2007; Snay and Soler 2008) and 50/70 km respectively. Both “small” and “large” networks are useful for many applications (e.g. mobile mapping, precise positioning, cadastral surveying) (Piras et al. 2009) if geodetic instruments are employed but less useful if mass-market instruments are used, or if the inter-station distance between master and rover increases (Won et al. 2015). The use of single-frequency GNSS receivers brings with it certain limits (Bevly 2004) in obtaining a correct fixing of phase ambiguities (Grejner-Brzezinska et al. 2007; Kim and Langley 2002). The aforementioned factors play a crucial role in obtaining centimeter-level positioning in rapid time and with a high degree of reliability (Chen et al. 2015).

Furthermore, the contribution of L1 mass-market permanent stations in CORS networks both for geodetic and low-cost receivers has been investigated; in particular, we describe how the use of network products can improve the accuracy and precision of a rover at distances of 2.5, 5, 10 and 15 km from the nearest station.

2 GNSS L1 Mass-Marker Receivers as Rovers in CORS Networks

Today, when we speak of GNSS Network for Real Time Kinematic (NRTK) positioning, we have in mind a classic network of permanent stations composed of dual-frequency and multi-constellation receivers (hereinafter called a “classic” network). In this context, various studies (Coulot et al. 2014; Dabove et al. 2014) have been conducted in order to estimate precisions and accuracies available with different kinds of instruments. Some tests have also been performed with rover receivers composed of geodetic instruments, while others have examined mass-market instruments (Dabove and Manzano 2014).

First of all, it is necessary to clarify what the Authors mean by the term “mass-market”: in this paper we consider to be mass-market GNSS receivers those instruments capable of tracking both pseudorange and carrier-phase measurements on L1 frequencies alone, and which cost less than 500 € (Cina and Piras 2014). On this basis, the u-blox LEA-6T in its evaluation kit mode (EVK-6T) was chosen as being representative of this category, as described in a previous study by Dabove and Manzano (2014). Similarly, for the antenna, a model was chosen that had been tested previously with resultant high-level positioning accuracy. The Garmin GA38 will be considered as our rover antenna because of its very low cost (about 50 €) and since it is, nevertheless, able to track both GPS and GLONASS satellites, thus allowing multi-constellation positioning. As mentioned in the introduction, two different CORS network configurations have been considered (Fig. 1). Both networks are managed by two currently available network software packages: the Leica GNSS Spider v.4.3.0.4633 provided by Leica Geosystems® and the GNSMART v. May 2015 provided by Geo++®, in combination with the two differential corrections available today for single-frequency receivers: the Virtual Reference Station (VRS®) and the Nearest (NRT). To perform NRTK positioning, the RTKLIB v.2.4.2 software was used (Takasu and Yasuda 2006); in particular the RTKNAVI tool was utilized, as described in Takasu and Yasuda (2006), Manzano and Dabove (2013). This software package makes it possible to fix phase ambiguity thanks to the ratio test: in this case the threshold value is equal to 3. This means that if the phase ambiguities are fixed as integer values, centimeter accuracy can be obtained and one may speak of fixed (FIX) positions. In contrast, with no ambiguity fixing, one speaks of the float (FLT) solution which only provides sub-meter accuracy. The coordinates of TEST point (Fig. 1) and all reference stations were estimated through a post-processing approach using a geodetic receiver and antenna

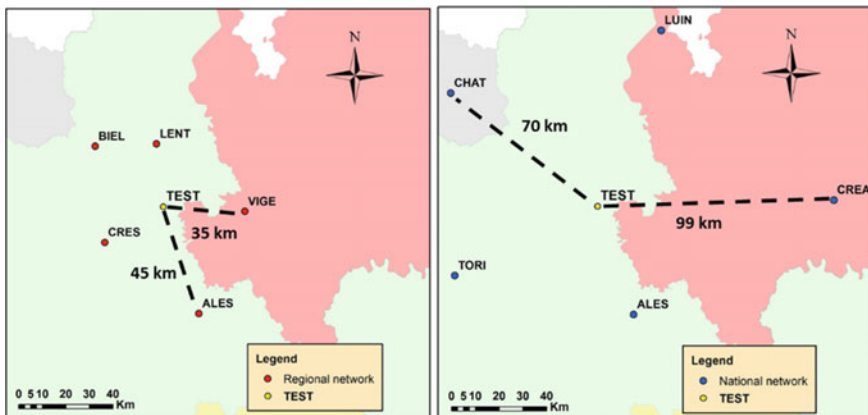


Fig. 1 Inter-station distances of “small” (*left*) and “large” (*right*) networks

Table 1 Results obtained considering the “small” and “large” network and the mass-market receiver as rover

		Small network	Large network	
RTKNAVI Config	Differential correction	2D accuracy at 95% (m)	3D accuracy at 95% (m)	2D accuracy at 95% (m)
Kinematic fix and hold	VRS	0.03	0.06	0.11
	NRT (35 km)	~0.04	~0.04	0.18
Static fix and hold	VRS	0.04	0.03 ÷ 0.04	0.07
	NRT (35 km)	~0.03	~0.02	0.15

and considering a static session of 24 h with a sampling rate of 1 s. The accuracy of these coordinates is about 2 mm. In order to determine the precision and accuracy currently available using a single-frequency and multi-constellation (GPS + GLONASS) mass-market receiver, the u-blox EVK-6T with the low-cost Garmin GA38 antenna were installed on the TEST site for 24 days of acquisition, with a rate of 1 s, with a kinematic positioning, resetting the phase ambiguities each time they are declared fixed. Both Spidernet and GNSMART software packages were utilized to estimate the accuracy obtainable with such receivers but no appreciable differences were found between these two software packages in use: the positioning results obtained by the mass-market receiver in a regional network (inter-station distances of about 25–30 km) are very good both in terms of precision and accuracy if the phase ambiguities are fixed, as it is possible to see from Table 1 (the results shown are obtained using GNSMART software). On the basis of previous studies (Dabove and Manzano 2014), this table only presents “fix and hold” method of integer ambiguity resolution. Considering both “static fix and hold” and “kinematic fix and hold” ambiguity resolution methods available in RTKLIB, accuracies are less than 6 cm using GNSS mass-market receivers, which is suitable for a large number of applications (mobile mapping, cadastral survey etc.) (Guarnieri et al. 2013).

No substantial differences are obtained with respect to (Dabove and Manzano 2014) where a single constellation mass-market receiver was employed as a rover to perform positioning within similar networks. In this case (Table 1) the use of a mass-market dual-constellation receiver does not offer any benefits. Notwithstanding this, an accuracy of about 10 cm can be achieved (Table 1) even with a “small” network.

In addition, time to first fix (TFF) analysis was performed, and after 24 days we had obtained more than 17,000 fixed solutions, which means one FIX solution more or less every 2 min (Dabove and Manzano 2016). This value is reasonable: considering the “large” network TFF is about 175 s (less than 3 min) while it is 81 s if a “small” network is considered. In both cases, the best results are obtained with VRS correction.

3 A “Mixed” Network: Test Set-up and Results

In order to test the use of a GNSS L1 mass-market receiver, a new ad hoc network with “medium” inter-station distances (about 45 km) was defined. The tests, like those of the previous section, were performed on a new network, shown in Fig. 2. In this case, the rover is called TEST and its position is about 19 km from the nearest permanent station, called NOVR. Both the coordinates of TEST and all reference stations were adjusted with the Bernese 5.0 software, using a static session of 2 days with a sampling rate of 1 s in this case too. The characteristics of the NRTK positioning are the same as those described previously. Neither in this case (Table 2) are substantial differences in the quality of rover positioning obtained if Spidernet and GNSMART[®] software packages are employed: the degrees of accuracy obtained are comparable with those achieved previously (Table 1).

In the “medium” NRTK network the TTF period is also estimated: as it is possible to see from Table 3, a generic user must wait at least 3 min for a FIX position if VRS correction is used. At this point, the challenge is to create a “mixed” network where all sites are composed of dual-frequency and multi-constellation receivers and antennas except for TEST, which is equipped with the same mass-market receiver and the low cost antenna previously described.

Both network softwares were tested but with Spidernet it is not possible to consider a single-frequency receiver as a permanent station. Thus, while Spidernet can, in fact, manage pseudorange and carrier phase measurements, these data

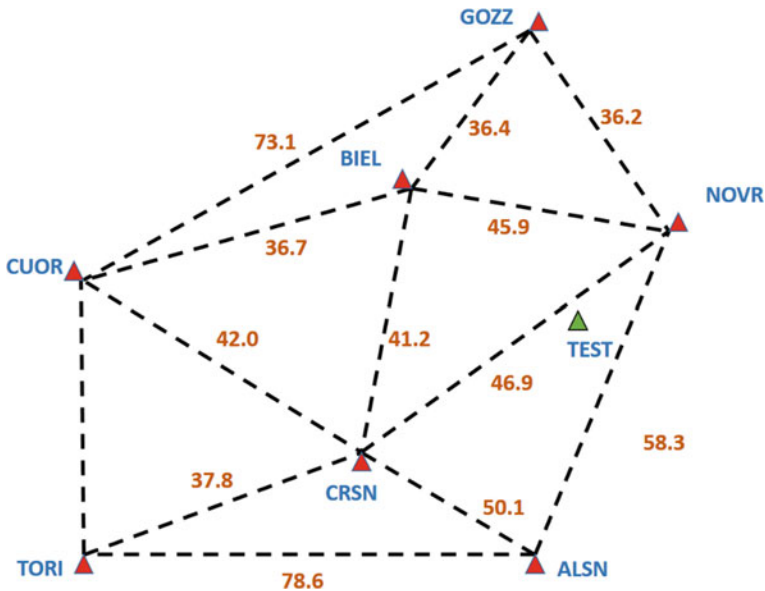


Fig. 2 The new “medium” network: the master stations (red triangles) and the rover receiver (in green). All distances are in kilometers

Table 2 Accuracies obtainable with the network shown in Fig. 2 and TEST as rover receiver

RTKNAVI configuration	Differential correction	3D accuracy at 95% (m)
Kinematic fix and hold	VRS	0.04
	NRT (19 km)	~0.03
Static fix and hold	VRS	0.03 ÷ 0.04
	NRT (19 km)	~0.02

Table 3 Time to first fix period estimated for different corrections considering the “medium” network shown in Fig. 2 and TEST as rover receiver

Correction type	n° of correct/total FIX	mean TTF	max TTF (s)
VRS	52/78	78 s ± 31 s	183
NRT	41/76	89 s ± 48 s	219

cannot be used for network calculation. GNSMART, on the other hand, exhibits a different behavior. Only in this case can a “mixed” network be examined as both single and dual-frequency receivers can be used as master stations. It is important to stress that the GNSMART software requires approximately 8 min to fix the ambiguity phase for all stations in the network (this is the same time if a network with only geodetic receivers is considered). With a mixed network, and using GNSMART as network software, some tests have been carried out to determine the performances of NRTK positioning with geodetic and mass-market receivers in a mixed network. Test sites 2.5, 5, 10 and 15 km away from TEST have been examined in order to verify precision and accuracy obtainable (Fig. 3).

For these tests, the same instruments installed on TEST site are employed for the rover; different network products, such as VRS and Nearest (NRT) corrections, are used with the RTKNAVI tool for real-time positioning of the mass-market rover receiver, with an updating rate equal to 1 s. The results obtained are somewhat particular: even if the phase ambiguities are fixed for the networks stations, no FIX positions are available for the rover receiver considering all differential corrections, and only float solutions are obtainable. This behavior pertains even where a geodetic (Leica 1230 + GNSS) receiver functions as rover. On the other hand, the float solutions are very good even when the low-cost instrument is employed: the difference between the estimated and the reference positions is about 10 cm if the distance to the nearest station is less than 2.5 km, as it is possible to see from Table 4. In this context, these results are useful only for traffic control purposes or cartographic applications: it could be very interesting to apply this network configuration to real-time monitoring of landslides in order to gain a deeper knowledge of the behavior and movements of the landslide itself.

If the distance between rover and nearest station (also known as the baseline) increases, accuracy does indeed decrease. However, if the difference in distance is in the order of 5 km, the accuracy is in the range of 20 cm, which is useful for many applications, such as mobile mapping, traffic control as well as cartographic applications. The results obtained if the baseline increases are of no particular

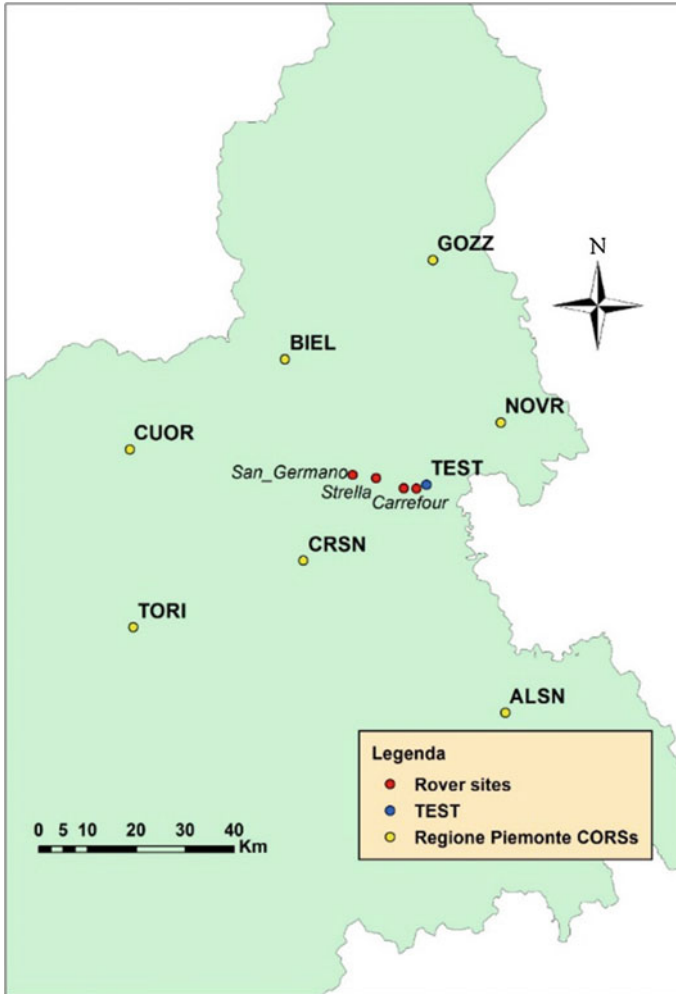


Fig. 3 Rover test sites (in red), CORS networks (in yellow) and TEST station (in blue)

Table 4 Results of mass-market receivers in a mixed network: only FLT solutions are available

Test site	d from TEST (km)	Correction	Mass-market 3D accuracy at 95% (m)	
			Geodetic	Geodetic
Carrefour	2.5	VRS	0.09	0.05
		NRT	0.07	0.07
Cascine Strà	5	VRS	0.18	0.15
		NRT	0.22	0.18
Strella	10	VRS	0.53	0.44
		NRT	0.60	0.51
San Germano	15	VRS	0.56	0.50
		NRT	0.61	0.55

interest: in these cases the accuracies obtained are greater than 50 cm, which is not useful for the previously cited purposes. When employing a geodetic receiver as rover (Table 4), good results can also be obtained: if the distance between rover and the nearest station is lower than 5 km, the accuracy is better than 20 cm.

In summary, the results obtained preclude the possibility of performing NRTK positioning in mixed networks as no software currently makes this kind of survey possible. Despite this fact, a new possible solution could be adopted, for example, for landslide monitoring: the idea is to consider all stations (mass-market and geodetic) as masters and analyze the variation of coordinates in order to decide if a displacement occurs. This is possible thanks to GNSMART: the a priori coordinates can be weighted in different ways by the network manager. It is therefore possible to use a stronger constraint weight for geodetic receivers and a looser constraint weight for mass-market ones. At the same time, this software can determine the difference between estimated and a priori coordinates in real time. This is useful because, coupled with some statistical techniques, it makes it the possible to analyze whether a difference is due to measurement noise or represents a real displacement.

54 initializations are made in order to analyze the accuracy of L1 and L1 + L2 CORSs. Some statistical analysis is performed also in order to focus on this aspect: analyzing the behavior of four days of data, after a network initialization of about 8 min, the accuracy of the TEST station is no different from that of the other CORSs, which is to say, about 3 mm in planimetry and 6 mm in altimetry components.

4 Conclusions

The benefits of using a single-frequency receivers are discussed in this paper and their performances in a CORS network were examined.

Two different networks, are investigated with the creation of a “small” and a “large” network. The results obtained using an L1 mass-market GNSS receiver as rover are very good since an accuracy of about 5 cm can be achieved after the fixing of phase ambiguity. Furthermore, TTF is very short: a user need wait no more than 2 min to obtain a fixed solution. If the inter-station distance increases, accuracy does obviously decrease but, notwithstanding this, the precision obtainable is useful for many applications, such as mobile mapping and traffic control.

Subsequently, this kind of receiver has been used as a permanent station, coupled with the same antenna, in an RTK Network with geodetic receivers. In this context, particular results are obtained because no single network software is yet suitable for providing real-time products for “mixed” networks. Nevertheless, as of now, these receivers can be used as masters in real-time network calculation. With GNSMART software it is possible to manage a “mixed” network, and a possible solution could be adopted taking all stations (mass-market and geodetic) as

masters and analyzing the variation of coordinates in order to decide whether a displacement occurs: thus it is possible to compare the difference between estimated and a priori coordinates in real time to analyze whether the difference is due to measurement noise of or constitutes a real displacement.

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