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PM

Test measurements by Lantmäteriet with RTK and Galileo in SWEPOS up to January 2017

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Abstract

SWEPOS Network RTK Service has for many years used the combination GPS and GLONASS. With the recently fast development of Galileo, it is now desirable to also use this system. SWEPOS-based test measurements with RTK and Galileo have been carried out with the start in April 2016, initially only as single-station RTK, but later also as network RTK. Initially only one rover brand has been used, but it has now become possible to also use other rover brands. The so far performed test measurements indicate an improvement in availability if Galileo satellites are added to five–six GPS satellites compared with no Galileo satellites (more fixed solutions and shorter time to fixed solutions).

Background

SWEPOS® is the national augmentation system for satellite positioning in Sweden operated by Lantmäteriet (the Swedish mapping, cadastral and land registration authority). It consists of more than 370 permanent reference stations for GNSS which receive signals from the GNSS satellites and send them to the control centre of SWEPOS at Lantmäteriet's main office in Gävle. The data is collected at the control centre where it among others is quality checked before it (together with data from some additional stations) is used for e.g. the positioning services of SWEPOS. The most important service is SWEPOS Network RTK Service which initially only used data from GPS satellites. In April 2006, the service started to offer data for the combination GPS and GLONASS.

During recent years, SWEPOS has become prepared for Galileo and new satellite signals from other existing GNSS (Wiklund, 2016). After a launch of four Galileo satellites on November 17th 2016, the system now consists of 18 satellites in orbit (even though all of them are not fully operational), see Table 1. In connection with this, the European Commission on December 15th 2016 declared that Galileo had reached Initial Services, which is a milestone for the project. The possibilities to use these satellites together with other already existing systems like GPS and GLONASS are now evident. A few things still remain before mountpoints for the network RTK service where Galileo data is included can be opened. These are some functionalities

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in the network RTK software and that around fifty GNSS receivers in the SWEPOS network have to be replaced. Test measurements also have to be performed and such have been started and the so far carried out ones are reported in this PM. Galileo is expected to be fully operational with 30 satellites around 2020 and up-to-date status for the different GNSS is among others available in the travel report from the 2016 meeting within Civil GPS Service Interface Committee (CGSIC) (Alfredsson, 2016).

Table 1: *Total number of so far launched Galileo satellites. [1]Two satellites were launched on October 21st 2011 and additionally two were launched on October 12th 2012 where one can only send the E1 signal. [2]The first two satellites were launched on August 22nd 2014, but ended up in incorrect orbits which now have been improved and the four recently launched satellites are not operational yet.*

Satellite model	Year	Number	Active
Test	2005–2008	2	0
Prototype	2011–2012	4	3[1]
FOC	2014–	14	8[2]
Total	2005–	20	11

Method for test measurements carried out

SWEPOS-based test measurements with RTK and Galileo started during 2016 with a diploma work by Anna Berggren from Stockholm University (Berggren, 2016). Further tests have thereafter been carried out in order to find out what Galileo can contribute with. In all tests so far, only the combination Galileo together with GPS has been tested and compared with if only GPS was used in order to in that way find out differences in number of fixed solutions, time to fixed solution and standard uncertainty. All test measurements are carried out in the SWEPOS reference station network, initially only relative one station, so-called single-station RTK, but later also as network RTK. The network RTK tests have been performed in a small test network where all reference stations are equipped with GNSS receivers of the model Trimble Net R9. It has initially only been possible to use the rover brand Trimble (model R8-3 has been used), but now it is also possible to use other rover brands. All test measurements have been carried out on points with good visibility towards the satellites and with a cut-off angle of ten degrees.

In parallel with this, SWEPOS has also worked with implementing the new satellite system in the services, firstly in the network RTK service, and the goal is to implement Galileo in the service during 2017. The goal for the future is also that it will be possible to combine the Chinese system BeiDou with the other systems.

The test measurements have been surveyed both point by point and continuously according to:

- **Point by point:** Each measurement is a series of 10 positions during 10 seconds with a mean value calculated. Some GPS satellites were manually deactivated with a still acceptable PDOP value. A reinitialisation were performed between all measurements by disconnecting the rover equipment. If an ambiguity fixed solution was not obtained within 180 seconds, the measurement was treated as an unsucceed determination of a fixed solution.
- **Continuously:** Each measurement is continuously surveyed with an interval of one second without reinitialisation or a mean value calculated. All available GPS and Galileo satellites have been used.

Results from test measurements carried out

A compilation of the results from the test measurements carried out so far is seen in Table 2–8 below.

Table 2: *Test measurements with single-station RTK.*
Survey: *Point by point*
Time: *April 2016*
Observer: *Anna Berggren, Stockholm University (diploma work)*
Point: *Control point in Stockholm, on tripod*
Reference station: *SWEPOS station Mosebacke*
Distance: *1.2 km*

Satellites (number) GPS	Satellites (number) Galileo	Measurements (number)	Successful fixed solutions (%)	Mean value of time to fixed solution (sec)	Standard uncertainty horizontally (mm)	Standard uncertainty vertically (mm)	Mean value of PDOP (-)
5	0	41	88	28	7	16	4,1
5	2	61	93	16	11*	17	3,2
5	3	43	100	23	7	15	2,6
5	4	7	100	13	8	8	2,2
6	0	35	94	10	6	12	3,0
6	2	42	98	12	8	14	2,4
6	3	27	96	8	5	11	2,2
6	4	5	100	8	4	4	2,1

*8 mm if an outlier of 57 mm is removed.

Table 3: *Test measurements with single-station RTK.*
Survey: *Point by point*
Time: *May–June 2016*
Observer: *Marie Danielsson, KY Helsingborg*
Point: *The roof of Lantmäteriet, Gävle, on pillar*
Reference station: *SWEPOS station Mårtsbo (Gävle excluded)*
Distance: *10.6 km*

Satellites (number) GPS	Galileo	Measurements (number)	Successful fixed solutions (%)	Mean value of time to fixed solution (sec)	Standard uncertainty horizontally (mm)	Standard uncertainty vertically (mm)	Mean value of PDOP (-)
5	0	45	80	44	13	26	3,4
5	2	48	88	30	15	37	2,7
5	3	45	98	43	17	42	2,5
5	4	13	92	30	28	43	2,2
6	0	37	100	10	15	16	2,5
6	2	41	100	15	13	24	2,4
6	3	40	95	10	13	26	2,2
6	4	12	100	10	13	29	2,0

Table 4: *Test measurements with single-station RTK.*
Survey: *Point by point*
Time: *September–November 2016*
Observer: *Tarek Al-Kayat and Dan Norin, Lantmäteriet*
Point: *The roof of Lantmäteriet, Gävle, on pillar*
Reference station: *SWEPOS station Gävle*
Distance: *50 metres*

Satellites (number) GPS	Galileo	Measurements (number)	Successful fixed solutions (%)	Mean value of time to fixed solution (sec)	Standard uncertainty horizontally (mm)	Standard uncertainty vertically (mm)	Mean value of PDOP (-)
5	0	35	91	38	4	6	3,4
5	2	16	94	38	4	6	3,0
5	3	16	100	25	4	7	2,4
5	4	33	97	7	3	7	2,0
5	5	5	80	5	2	4	1,7
6	0	29	100	7	3	5	2,7
6	2	19	100	7	3	5	2,5
6	3	48	100	3	4	6	2,3
6	4	21	100	2	3	4	2,0
6	5	13	100	2	3	4	1,6

Table 5: *Test measurements with network RTK (VRS).*
Survey: *Continuously*
Time: *November 2016*
Observer: *Stefan Öberg and Fredrik Stedt, Lantmäteriet*
Point: *The roof of Lantmäteriet, Gävle, on pillar*
Closest reference station: *SWEPOS station Mårtsbo (Gävle excluded)*
Distance: *10.6 km*

○ = Reference stations
△ = Point

Satellites (mean number) GPS	Galileo	Measure-ments (mm)	Standard uncertainty horizontally (mm)	Standard uncertainty vertically (mm)	Mean value of PDOP (-)
9	3	29253	6	10	1,8
9	-	59335	8	13	2,0

Table 6: *Test measurements with network RTK (VRS).*
Survey: *Continuously*
Time: *December 2016–January 2017*
Observer: *Stefan Öberg and Fredrik Stedt, Lantmäteriet*
Point: *Rörberg airport, Gävle, on pillar*
Closest reference station: *SWEPOS station Gävle*
Distance: *12.0 km*

○ = Reference stations
△ = Point

Satellites (mean number) GPS	Galileo	Measure-ments (number)	Standard uncertainty horizontally (mm)	Standard uncertainty vertically (mm)	Mean value of PDOP (-)
10	4	4580	4	6	1,6
8	-	6425	5	8	2,1

Table 7: *Test measurements with network RTK (VRS).*
Survey: *Point by point*
Time: *December 2016–January 2017*
Observer: *Stefan Öberg and Fredrik Stedt, Lantmäteriet*
Point: *The roof of Lantmäteriet, Gävle, on pillar*
Closest reference station: *SWEPOS station Mårtsbo (Gävle excluded, i.e. the same network as in the map in Table 5)*
Distance: *10.6 km*

Satellites (number) GPS	Galileo	**Measurements** (number)	**Successful fixed solutions** (%)	**Mean value of time to fixed solution** (sec)	**Standard uncertainty horizontally** (mm)	**Standard uncertainty vertically** (mm)	**Mean value of PDOP** (-)
5	0	23	100	51	11	15	3,4
5	2	42	93	37	8	19	3,5
5	3	108	98	38	9	17	2,6
5	4	42	100	23	9	22	2,3
5	5	18	100	48	8	29	2,2
6	0	58	100	9	7	10	2,7
6	2	11	91	2	9	22	2,7
6	3	49	100	6	12	32	2,3
6	4	18	100	5	8	10	1,9
6	5	0	-	-	-	-	-
Please observe that Table 8 comprises a corresponding result, but with another rover brand.							

Table 8: *Test measurements with network RTK (VRS).*
Survey: *Point by point*
Time: *December 2016–January 2017*
Observer: *Stefan Öberg and Fredrik Stedt, Lantmäteriet*
Point: *The roof of Lantmäteriet, Gävle, on pillar*
Closest reference station: *SWEPOS station Mårtsbo (Gävle excluded, i.e. the same network as in the map in Table 5)*
Distance: *10.6 km*

Satellites (number) GPS	Galileo	**Measurements** (number)	**Successful fixed solutions** (%)	**Mean value of time to fixed solution** (sec)	**Standard uncertainty horizontally** (mm)	**Standard uncertainty vertically** (mm)	**Mean value of PDOP** (-)
5	0	29	93	10	10	10	3,6
5	2	57	91	8	12	12	3,2
5	3	62	100	11	6	11	2,5
5	4	131	100	3	7	12	2,5
5	5	46	100	6	9	13	2,8
6	0	54	96	9	7	15	3,5
6	2	0	-	-	-	-	-
6	3	56	100	2	4	13	2,9
6	4	89	100	2	7	11	2,4
6	5	14	93	15	10	14	2,5
Please observe that Table 7 comprises a corresponding result, but with another rover brand.							

Conclusions

The results generally show that both test measurements with single-station RTK and with network RTK give a picture that there is an improvement to some extent with Galileo included regarding successful fixed solutions and shorter time to fixed solutions. It is however more difficult to evaluate if the standard uncertainty is affected by the use of Galileo satellites.

In the tests with single station RTK, it is also seen that the distance to the reference station has large effect on the result, which is earlier well-known. Mainly the standard uncertainty, but also the time to fixed solution are shortened with a shorter distance to the base station. The tested distances are 10 km, 1.2 km and 50 metres.

The tests with network RTK have so far only been carried out on distances of approximately 10–12 km from the closest physical reference station. They give a similar result as for the tests with single-station RTK regarding successful fixed solutions and time to fixed solution. There is also an indication that the standard uncertainty could be lower when Galileo is used. If the standard uncertainties are compared with the ones for single-station RTK, they are generally a bit lower for network RTK, perhaps mainly horizontally (if the test with a distance of only 50 metres to the base station is disregarded).

Further test measurements are desirable in order to achieve a clearer picture on how the use of Galileo could improve network RTK. It is also assumable that the use of Galileo in the rover equipment will improve, which later on will give positive effects which not have been possible to see in the test measurements performed so far.

References

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