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Assessment of sparse GNSS network for network RTK

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Abstract: We tested the accuracy and usability of a sparse GNSS reference station network for network RTK (NRTK) using the Finnish permanent GNSS network FinnRef. We modified the configuration of the FinnRef network stations used in NRTK computation. This allowed us to perform the test both inside and outside of the network area using different NRTK methods and two different RTK receivers. In the test area the average distance between the FinnRef stations was 160 km. As a comparison, we tested also with the commercial Trimnet and HxGN SmartNet positioning services operated by Geotrim Oy and Leica Geosystems Finland, respectively. Tests showed that the horizontal and vertical rms of Trimnet service was 16 mm and 40 mm, and of HxGN SmartNet service 23 mm and 48 mm. The best rms for the sparse NLS (National Land Survey of Finland) Service was 22 mm and 56 mm. These results indicate that a good NRTK solution can be achieved with a sparser network than typically used. This study also indicates, that the methods for NRTK processing can also affect the quality of the solution.

Keywords: Accuracy, inter-station distance, network RTK, test field

1 Introduction

A single base GNSS reference station enables RTK corrections that allow measuring coordinate differences with respect to the reference station typically with 5-10 mm ± 0.5-1 ppm accuracy. The accuracy is distance dependent mainly due to atmospheric refraction and orbital errors and the effective measurement range is 10-20 km from the reference station (El-Mowafy, 2012). In order to overcome the limitations of the single base station RTK one can use the Network RTK (NRTK) concept. The NRTK increases the reliability and usability of the service. A network solution is not critically dependent on single reference stations and the service is operational even with a failure on a single station (Fotopoulos &Cannon, 2001).

With NRTK, GNSS signal propagation related errors may be estimated for the whole network area, and distance dependent errors will be highly reduced (Lachapelle & Alves, 2002). Usually inter-station distances between the reference stations in commercial NRTK services is less than 100 km (El-Mowafy, 2012), but it can be even 10 km in some special applications where higher height accuracy is needed. Disadvantages of the network solution are the increase of data transfer load and a need for an analysis center to compute the corrections in real-time. Network approach with real-time data communication and processing centers is a complex infrastructure that requires costly implementation and maintenance of the quality service (Fotopoulos &Cannon, 2001).

Components of the NRTK are the GNSS network, a processing center and users. Reference network consists of a number of GNSS stations streaming GNSS data to the processing center. The processing center solves for ambiguities and network corrections that are interpolated to cover end users positions. The most widely used approaches to create NRTK data/corrections are the Virtual Reference Station (VRS) concept (Landau et al., 2002) and Master Auxiliary Concept (MAC) (Brown et al., 2006) and its variation master-auxiliary corrections (MAX). Individualized master-auxiliary corrections (i-MAX), Pseudo Reference Station (PRS) concept as well as Flächen Korrektur Parameter (FKP) technique are also used. Data and corrections can be provided for the end user in different ways. Typically services provide data and corrections using RTCM 2.x, RTCM 3.x, CMR or/and CMR+ formats and users can access data streams through Internet via NTRIP casters using 2-4G modems.

NRTK using the typical 50-70 km interstation distances is widely studied and shown to be accurate and reliable (Aponte et al., 2009; Edwards et al., 2010). Wang et al. (2010) tested commercial NRTK using inter-station dis-

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tances of 69 km, 118 km and 166 km. They compared VRS, i-MAX and VRS and concluded that VRS worked better in 69 km network and MAX had the best ambiguity fix percentage in the sparse network. They concluded that the performance of NRTK is weaker in sparse networks: the initialization times were longer and risk for false initializations grew to 18%, 20%, 13% and 25% for i-MAX, MAX, Leica VRS and Trimble VRS. In a normal network the VRS risk for false initialization was less than 1%. (Feng & Li, 2008) showed that in the near future new triple-frequency signals allow to lengthen interstation distances up to 180 km and still obtain positioning in centimeter level.

In this paper we use PRS, MAC and FKP from NLS (National Land Survey of Finland) positioning service and use as comparison VRS and MAX from commercial services. The relations of the different methods are summarized in Fig. 1 (Odijk & Wanninger, 2017). All the methods include the same steps. First, the data are streamed to the processing center where the ambiguities are resolved and observations are brought into the same ambiguity level after which the coefficients for distance dependent errors are estimated. In the third step the virtual reference data are created in the vicinity of a rover receiver and finally a differential solution between the virtual station and the rover are processed. The main differences between the methods are mainly the step when the data are sent to the rover and at what level the processing is done at the processing center.

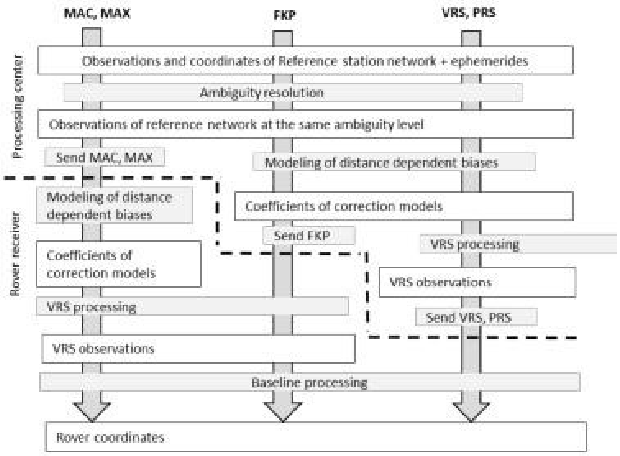

Figure 1: Principles of the NRTK methods and how the processing is divided between processing center and rover receiver. Modified from (Odijk & Wanninger, 2017).

In MAC and MAX the observations of the master station and differences to auxiliary stations at the same ambiguity level are send to the rover and the rover makes the error modelling. In FKP the error modelling is done at the server and coefficients are send to the rover together with the master reference station data. In VRS, virtual data are created at the server to the coordinates of the rover and streamed to the rover. PRS is a similar concept to VRS, the corrections are processed to the user coordinates, but virtual data is done further away (4.3 km in the NLS positioning service) from rover coordinates.

FinnRef network was originally constructed for the frame of the Finnish official coordinate system and many of its technical solutions differ from typical NRTK-networks. For instance, FinnRef stations locate usually remote from city centers in the interference free environment, choke ring GNSS-antennas at the stations are individually calibrated and antenna masts have been mounted straight into bedrock. These solutions make FinnRef technically more sophisticated compared to the regular NRTK-use-only designed networks, and may enhance performance level of FinnRef network in the NRTK use.

In this paper we study the NRTK performance of a sparse FinnRef network. The positioning service of the National Survey of Finland (NLS) utilizes a sparse FinnRef GNSS network (referred in this paper as NLS Positioning Service). Our main interest was to test the performance of the network RTK when inter-station distance between the actual reference stations is longer than 50-70 km which is normally used in commercial networks. We aim to show that performance using a sparse network is compatible with more dense commercial networks. We describe here the test field created for the purpose, analyze FinnRef performance in NRTK use and compare the results with commercial services by Geotrim Oy and Leica Geosystems Finland.

2 Networks and methods

2.1 Finnish permanent GNSS network FinnRef

The National Land Survey of Finland, NLS, and its research unit, The Finnish Geospatial Research Institute FGI, operate FinnRef network that has 20 base stations (Fig. 2). The average distance between stations is 200 km, but the network is a bit denser in southern Finland than in the northern parts of the country. The primary function of FinnRef is to define the reference frame in Finland as a part of EUREF Permanent GNSS Network (Koivula et al., 2017), offer time series for 3-D crustal deformation determination, and offer an open real-time DGNSS service (Feng & Li, 2008; Odijk & Wanninger, 2017).

A special care has been taken for site selection and majority of the stations are built on 3-metre high steel masts fastened directly on the solid bedrock. Mast construction is narrowed on the top to minimize the disturbing multipath reflections from the mast itself. Stations are equipped with Javad Delta-G3T (JAVAD TRE_G3TH DELTA) receivers and Javad choke ring antennas with SCIGN hemispherical radar domes (JAVRINGANT_DM SCIS). All antennas are individually calibrated by Geo++ in Germany using a calibration robot (Wübbena et al., 2000). Individual calibration takes into account the small differences between the antennas even when the antennas of the same type are used. A more detailed description of the FinnRef network is given in (Feng & Li, 2008; Odijk & Wanninger, 2017).

All FinnRef data are streamed to the analysis center of the NLS. GNSMART (GNSS State Monitoring And Representation Technique) software by Geo++ is used for error modelling and data distribution (http://www.geopp.de/gnsmart/. In order to improve the error estimates GNSMART models also site specific errors like multipath. These corrections are applied in the network processing. This procedure should strengthen the error modelling and therefore improve the accuracy of the NRTK corrections. In this study MAC and FKP, corrections were transferred to the roving receiver in RTCM 3.1 and PRS in RTCM 3.0 formats using NTRIP protocol.

2.2 Commercial networks

Commercial Networks operated by Geotrim Oy and Leica Geosystems Finland are included in this study to get a comparison to the commercial state-of-art services. The GNSS antennas of both services have type calibration values instead of individual calibration. In type calibration it is assumed that all the antennas of the same type have identical calibration values. Both services provide corrections that enable users to get their position directly in the national EUREF-FIN reference frame.

Geotrim Oy is the oldest NRTK provider in Finland operating Trimnet network (Figure 2) that is based on the VRS technology. They have over 100 permanent GNSS stations and their products covers the accuracy classes of 1 mm, 1 cm, 10 cm, 30 cm and 50 cm. The stations are typically equipped with rooftop Trimble Zephyr antennas and NETR9 receivers. We used the VRS data from their service in Trimble's own CMR format.

Leica Geosystems Finland operates HxGN SmartNet (Figure 2) which has approximately the same station density as Geotrim's network. SmartNet is equipped with Leica GR10 receivers and LeiAR10 antennas, mostly placed on rooftops. They offer NRTK data with accuracies from centimeters to decimeters. We used MAX corrections through their NTRIP caster in RTCM 3.1 format.

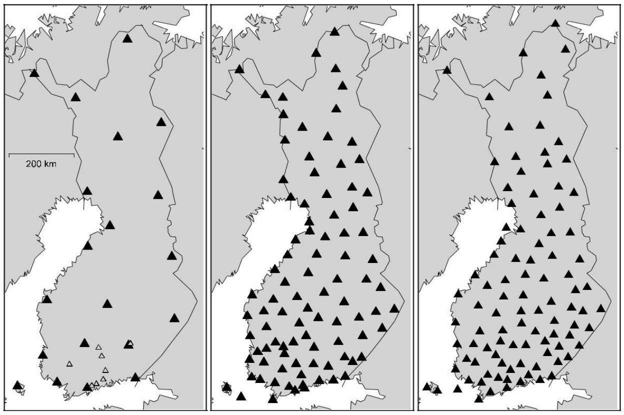

Figure 2: Nationwide NRTK networks in Finland. FinnRef (left) is operated by the FGI/NLS, TrimNet (middle) is operated by Geotrim Oy and HxGN SmartNet (right) is operated by Leica Geosystems Finland. Test points are shown with small white triangles in the FinnRef-picture.

2.3 Test field and the network configuration

We created a test field to Southern Finland where mean inter-station distance in the FinnRef-network is about 160 km. For the test field we chose eight benchmarks from the southern Finland (Table 1 and Fig. 2-4). All test points belong to the NLS benchmark register and they have official EUREF-FIN coordinates that are considered as true values. All except one are on the bedrock and they have an unobstructed visibility to the sky at least above 15 degrees elevation angle, and low multipath surrounding.

Test measurements were made in the same test field using two reference station configurations for NLS positioning service. Commercial services were used without modifications. In the interpolation measurements eight test points T1-T8 are located inside the reference network (Fig. 3). In the extrapolation measurements the test points are located outside the reference station network (Fig. 4). During the interpolation test all FinnRef reference stations were active, except in measurements at the Mikkeli test point T8 where the nearest reference station (MIK3) was temporarily removed from the NLS Positioning Service. This way we were able to get longer distances to the nearest reference stations than in the fully operational FinnRef

Table 1: Test points T1-T8. ID was given when a benchmark is originally established. D_{in} gives the distance to the closest FinnRef station when full network is utilized and D_{ext} gives the value when test points are in the extrapolation area (see Fig. 2 and 3).

Point	ID	Ground	D_{in} [km]	D_{ext} [km]
T1	06M5351	Bedrock	18.8 (MET3)	-
T2	05M6050	Bedrock	35.8 (MET3)	148.5 (ORIV)
T3	92M5549	Bedrock	65.2 (MET3)	-
T4	86M1031	Bedrock	89.7 (MET3)	120.3 (ORIV)
T5	02M4590	Stone	74.7 (ORIV)	74.7 (ORIV)
T6	88M5049	Bedrock	51.1 (ORIV)	51.1 (ORIV)
T7	03M6050	Bedrock	75.1 (TUO2)	-
T8	91M1905	Bedrock	122.3 (VIR2)	-

network is possible. In the interpolation measurements distances to the nearest FinnRef station varied from 18.8 to 122.3 kilometers.

Outside the reference station network the test measurements were made at four test points (T2, and T4–T6). The test points were the same as in the interpolation measurements. In the extrapolation test measurements four southernmost FinnRef stations were deactivated in the NLS Positioning Service. Distances to the nearest FinnRef station varied from 51.1 to 148.5 kilometers.

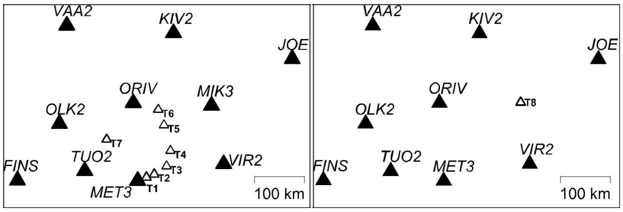

Figure 3: Test points and reference station configurations for interpolation tests. FinnRef stations are marked with black triangles. On the left hand side are the test points T1-T7 where the complete FinnRef network was active. On the right hand side is the Mikkeli test point T8 where the nearest FinnRef station (MIK3) was deactivated for the measurements. For geographical location compare with Fig. 2.

2.4 Test measurement procedures

Tests were divided into two different cases. In the first case we used fully operational NLS service and as a comparison used both commercial services. In this case all the test points were inside the reference station networks (interpolation test). The second test case was an extrapolation tests where all the test points were outside the reference station network. This test was only performed with our NLS service. All tests were done between July 3 and September 16, 2014.

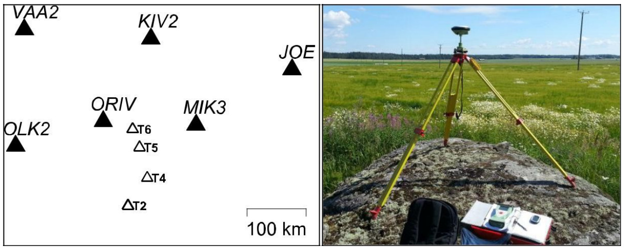

Figure 4: On the left there are the reference stations and test points T1 and T4-T6 which were used in the extrapolation test. During the measurements the southernmost FinnRef stations were deactivated. On the right is an example of the test setup at the test point. The RTK rover is set up on the benchmark using a tripod and tribrach with an optical plummet. For geographical location compare with Fig. 2.

Measurements at the test points were done at different times of the day on a tripod. The antenna was levelled and centered on a benchmark using a tribrach and an optical plummet. The antenna height was measured before and after observations. The uncertainty of centering the antenna in horizontal direction is estimated to be 1 mm and in height 1-2 mm.

Tests were made with Leica Viva GS14 (Firmware 5.50) and Trimble R10 (Firmware 4.90) GNSS receivers. In both receivers a 5 second averaging window was used. This means that the initialization was considered successful only if it remained 5 seconds and that the coordinate solution was averaged over 5 seconds. Cut-off angle was set to 10 degrees. Recording the initialization time was started when the receiver had the connection to the NTRIP caster and continued until the receiver informed that the initialization was successful. After the successful initialization, observation was saved and the internet connection was disconnected. This forced a new initialization for every observation. Every single initialization was waited for 10 minutes at most. If the initialization was not achieved by the time limit, a float observation was saved. If all of three first observations took a full 10 minutes, last three were waited for 5 minutes.

Fully operational networks (interpolation) were tested using 8 test points. Figure 5 illustrates the measurement procedure at a single test point. When Leica Viva was used we used MAC and FKP corrections from NLS network and as a comparison to MAC we used MAX from commercial Leica based SmartNet. Procedure began with three NRTK observations using MAC followed by three observations with MAX, MAC, MAX and finally six with FKP respectively. Every observation was made with a new ambiguity initialization. This procedure was repeated at every test point four times in different days and times of the day. With Trimble R10 the procedure was the same, but this time PRS and FKP were used from NLS service and VRS from commercial Trimble based TrimNet. All the test points were measured with both receivers. In total, 1152 observations were made in the interpolation measurements.

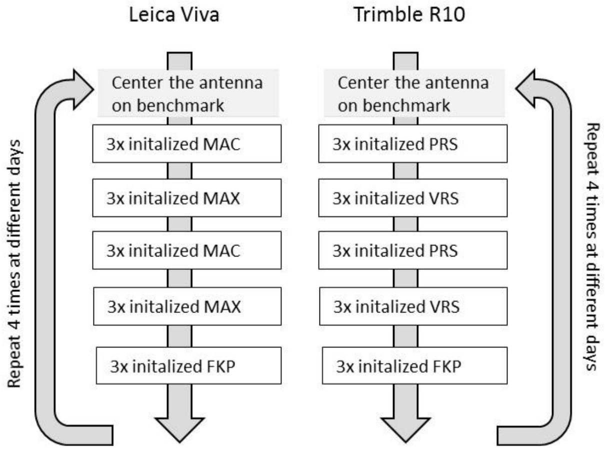

Figure 5: Test procedure at all the test points for fully operational (interpolation) networks. With Leica Viva receiver MAC, MAX and FKP corrections and with Trimble R10 PRS, VRS and FKP corrections were used. MAC, PRS and FKP corrections came from NLS service, MAX from SmartNet and VRS from Trimnet.

Tests at the extrapolation area were made at four points using the MAC and FKP corrections from the NLS Service. The measurement procedure (Fig. 6) was similar to that of the full networks. A total of 384 observations were made in the extrapolation network measurements.

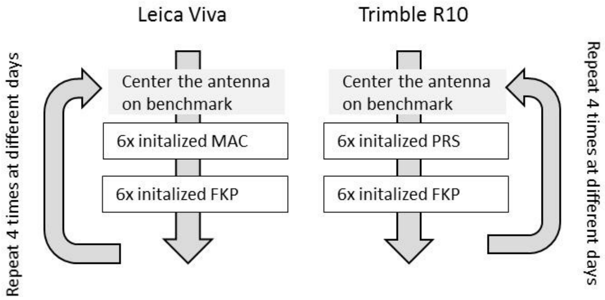

Figure 6: Test procedure for all the test point at the extrapolation area. With Leica Viva receiver MAC and FKP corrections and with Trimble R10 PRS and FKP corrections were used. All corrections came from the NLS service.

3 Results

3.1 Success Rate of Observations and Initialization Times

Summary of initialization times and success rates are given in Table 2. Initialization times refer to the cold initialization, i.e. the receiver has been reconnected to the server before every single initialization. We also investigated how the distance to the nearest reference station influences on initialization time or success rate.

In Table 2 all observations are categorized depending on the success of the initialization. An Initialized observation means that ambiguities have been solved for on the basis of the receiver information. A false initialization is an observation where the horizontal accuracy is worse than 10 cm, though receiver has informed that a correct initialization is reached.

Commercial Networks reached the initialization every time. Success rate of the all observations was for Trimnet 100% and for HxGN SmartNet 99.5%. On the average the initialization time for SmartNet was only 22 s, but it varied more than the initialization times from Trimnet. Initialization times between receivers are not directly comparable due to different user interface of two receivers. On the sparse NLS service R10 (PRS) reached 100% initialization rate with 99% success rate. FKP and MAC performed worse in NLS service and the initialization times were slightly longer than in the commercial networks.

On the extrapolation tests R10 (PRS) had still 100% initialization rate with 95.8% success rate. FKP performed a little worse and MAC was not reliable having only 49.0% probability for a successful initialized observation. Distance to the nearest reference station had no influence on the initialization time in any of the services.

3.2 Accuracy

Accuracies of tested NRTK-methods were evaluated by comparing all individual results to the actual coordinates of the benchmarks that were considered to be correct ones. The results with a fixed initialization were further categorized into correct and false initializations. Also the distance dependency to the closest reference station of the service (NLS, SmartNet or TrimNet) was checked. Finally the quality estimates given by the receivers were compared to the rms values obtained from this test.

Table 3 shows the rms values of all the results for both interpolation and extrapolation networks.

Table 2: Initialization times and their success rates. Initialized observations include all those observations where the receiver indicated a successful initialization. A false initialization means an observation where the plane accuracy is worse than 10 cm despite that the receiver informed that the initialization was successful. Correct observation is an initialized observation where the plane accuracy is better than 10 cm. All percentages have been calculated from the total number of observations (Obs). CM refers to the correction method, Rec to the receiver and Network to the NRTK service provider (Ext refers to the NLS network in an extrapolation mode). Init% tells the percentage of fixed initializations and I_Suc% tell the percentage of correct initializations. Init_{ini} and Init_{cor} give the initialization times of fixed and correctly fixed initializations, respectively, accompanied with their standard deviations.

CM	Rec	Network	Obs	Init%	I Suc%	Ini t_{ini}(s)	Std	Ini t_{cor}(s)	Std
MAX	GS14	Smart	192	100	99.5	22	47	22	47
VRS	R10	Trim	192	100	100.0	42	5	42	5
MAC	GS14	NLS	192	90.1	87.0	55	104	53	102
FKP	GS14	NLS	192	94.3	93.8	50	62	49	61
FKP	R10	NLS	192	99.5	97.9	52	56	49	40
PRS	R10	NLS	192	100	99.0	44	20	43	20
MAC	GS14	NLS (Ext)	96	81.3	49.0	106	127	70	87
FKP	GS14	NLS (Ext)	96	84.4	83.3	54	79	53	79
FKP	R10	NLS (Ext)	96	99.0	90.6	45	27	39	4
PRS	R10	NLS (Ext)	96	100	95.8	55	63	45	25

Both commercial networks show reliable results. Their ambiguity fix rate is high and rms of the results are in cm level. Horizontal and vertical rms values for Trimnet (VRS) were 1.6 cm and 4 cm and for SmartNet (Max) 2.8 cm and 5.2 cm, respectively. When only the correct initializations are taken into account (one false initialization is excluded from results), SmartNet's results improve to 2.3 cm and 4.8 cm. For NLS service the best performance was achieved with R10-PRS-pair (2.8 cm horizontal rms). MAC and FKP rms's are clearly worse. In the extrapolation test R10-PRS performance is the best with 4.5 cm horizontal and 10.3 cm vertical rms. Also R10-FKP results are convincing, when rms values are viewed, actually R10-FKP rms results are better in the extrapolation network than they are in the interpolation network. When the false initializations are removed from datasets, rms-values are almost equal in all test configurations.

Figure 7 shows the horizontal rms values at the test points and the fitted line through them showing the distance dependence of rms values. Distance effects of the horizontal rms are smaller in sparser Positioning Services networks than in denser Smartnet or Trimnet networks. For Trimnet distance dependency of the accuracy is 0.28 ppm and for Smartnet 0.54 ppm. For the NLS network the distance dependent part is less than 0.1 ppm for MAC and PRS and up to 0.34 ppm for FKP. In the extrapolation network the distance dependency was of the same magnitude.

Receivers give the quality estimation of the measurement, which exposes the precision of the observed position. The quality estimation is based on measurements conditions, and factors like satellite constellation and noise level of the GNSS signals. In Leica receivers the quality estimation is called Coordinate Quality (CQ) indicator. CQ value indicate expected rms value of the observations. Therefore, in an ideal case 68% of observations should be better than corresponding CQ-values. Quality information from Trimble R10 have 95%-confidence level (2 sigma). The indicators of R10-receiver were divided by two to convert them to the same confidence level where CQ-values of Leica receivers were.

Figure 8 shows how realistic the quality indicators are in the different test configuration. Both receivers give optimistic horizontal quality estimates compared to the rms of the observations. Most realistic quality estimations are generated by R10 in the NLS Service. R10 accuracy estimations are in the NLS service almost at expected 1 sigma level. Similar behavior cannot be seen in Leica results. Leica receivers give too optimistic accuracy estimations in all networks.

4 Discussion

Purpose of this research was to study the usability of a sparse GNSS reference station network for NRTK using the Finnish permanent GNSS network FinnRef. Capability of FinnRef in the NRTK use was tested by field measurements with two rover receiver and several NRTK methods. NRTK with longer inter-state distances has earlier been studied e.g. by Wang et al. (2010) and Gordini et al.

Table 3: Horizontal and vertical rms's of test configurations in the different initialization categories. All units are in meters.

			All Obs		Ini Obs		Correct Ini Obs	
MP	Rec.	Network	H rms	V rms	H rms	V rms	H rms	V rms
MAX	GS14	Smartnet	0.028	0.052	0.028	0.052	0.023	0.048
VRS	R10	Trimnet	0.016	0.040	0.016	0.040	0.016	0.040
MAC	GS14	NLS	0.531	1.089	0.217	0.116	0.026	0.073
FKP	GS14	NLS	0.675	1.346	0.087	0.098	0.023	0.052
FKP	R10	NLS	0.150	0.265	0.144	0.264	0.034	0.060
PRS	R10	NLS	0.028	0.060	0.028	0.060	0.022	0.056
MAC	GS14	NLS (Ext)	0.373	1.143	0.328	0.650	0.029	0.118
FKP	GS14	NLS (Ext)	0.298	1.356	0.079	0.353	0.027	0.092
FKP	R10	NLS (Ext)	0.053	0.066	0.051	0.066	0.026	0.050
PRS	R10	NLS (Ext)	0.045	0.103	0.045	0.103	0.027	0.095

(2006). Both studies indicate that position quality weakens in a sparser reference station network. FinnRef network has about 160 kilometers mean inter-state distance in the tested area. Both commercial services gave a good and reliable performance. The horizontal and vertical rms of TrimNet was 16 mm and 40 mm and of HxGN SmartNet 23 mm and 48 mm, respectively. When we compare the NLS network results to the commercial ones the most comparable NRTK-method-pairs in the test are PRS-VRS with Trimble R10 and MAC-MAX with Leica Viva. PRS and MAC observations were done in the sparse NLS network while VRS and MAX correction production based on the dense commercial networks. Results show that the performance of PRS in NLS network was nearly at the same level than VRS in the Trimnet network. PRS achieved practically the same amount of correct initializations and its rms was not remarkably poorer than results in commercial networks, i.e. 22 mm and 56 mm. Test pair MAX-MAC showed clearly dispersion in the results for the benefit of MAX-correction from the commercial Smartnet network. MAC concept seems to be more dependent on network density than PRS concept. Especially MAC did not perform well in the extrapolation area. Wang et al. 2010 concluded that MAX solution achieved better initialization success rate than VRS when recommended interstation distances were used. Our results showed 100% success rate for VRS and 99.5% for MAX. FKP-observations were collected by both receivers. FKP-results were better in both interpolation and extrapolation networks with R10 receiver.

False initializations on RTK measurements are impossible to be recognized using only one fix solution on the field. The probability for this becomes larger when sparse reference networks are used or measurements are done outside the reference station network. If measuring objects pointwise, repeated measurements with independent initializations (preferable at different time) will help detecting the false initializations. Results show that long initialization time is one indicator for false initialization. Both tested receivers tend to show optimistic quality indicator in the dense networks. Leica Viva gave optimistic quality estimations also in the NLS test networks. Quality indicators of Trimble R10 instead were more realistic in NLS networks than in the commercial Trimnet network.

Distance to the nearest reference station effects clearly the rms in the extrapolation network in the all configurations. Horizontal rms weakens 0.9–3.5 mm per kilometer outside the reference station network. MAC method has the largest distance effect. Inside interpolation network, NRTK- correction computation is based on several base station data and the role of the nearest station is not determinative.

This study indicates that at test area and conditions a sparse permanent GNSS network is a suitable frame for NRTK production. Position quality depends more on chosen NRTK-correction method than interstation distances in the reference network. PRS method with Trimble R10 receiver was the most efficient configuration in the tested interpolation network. The results were comparable with results from the denser commercial networks. This test configuration worked reliable even far outside the network in the extrapolation test. However, when using the sparse reference network the initialization times will be longer and the chance for false initializations becomes larger. In order to guarantee the right coordinate results we suggest using longer averaging window and repeated observations, preferably at different times. Also malfunctioning of the reference stations may lead to the situation where the net-

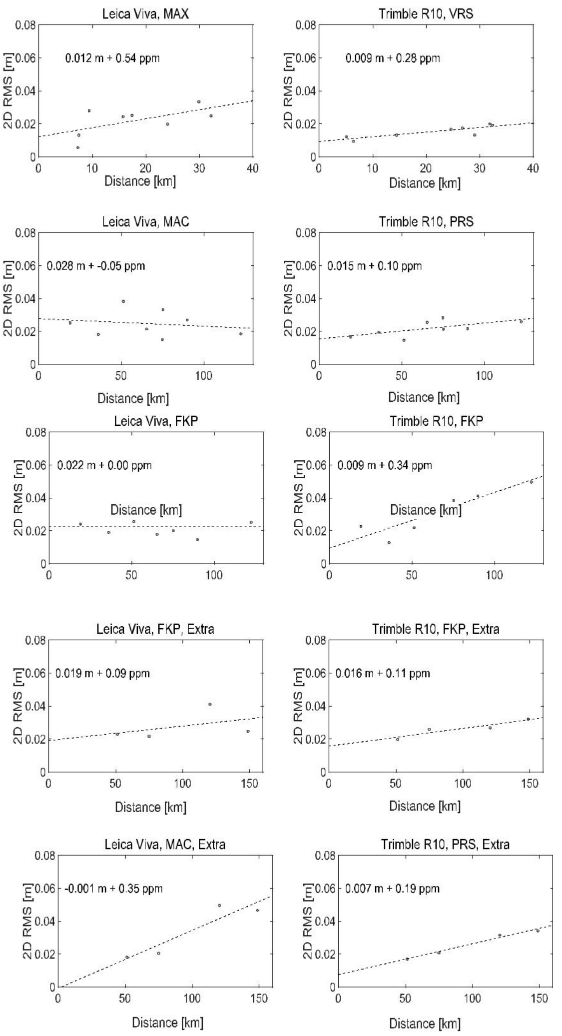

Figure 7: Horizontal rms at different test points. Float observations and failed initializations are excluded. The first row includes the results of commercial networks, and the following two rows refer to the NLS Positioning Service results in the interpolation measurements. The last two rows include the results of the extrapolation network measurements. Line is fitted to the plane RMS values. The equation of fitted lines are shown in the pictures.

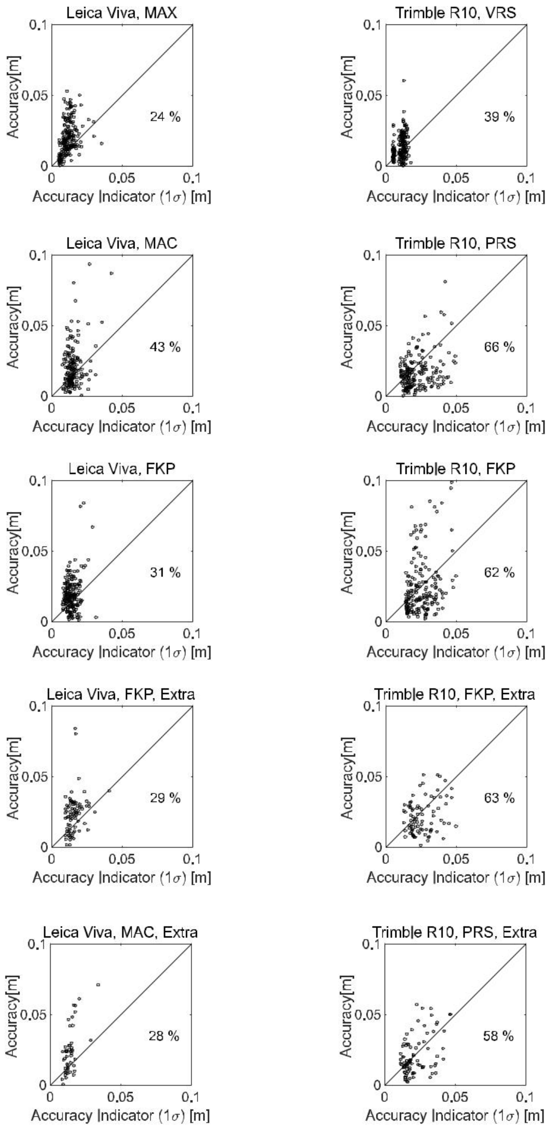

Figure 8: Horizontal rms (accuracy) vs quality indicator of the receiver. Percentage number in the pictures tells percentage of the observations where quality indicator is larger than rms. Failed initializations are removed from the datasets as well those observations where the receiver gave worse than 10 cm plane accuracy. First row shows the results of commercial networks, next two rows refers to the NLS Positioning Service results in the interpolation measurements and last two rows include the results of the extrapolation network measurements.

work is too sparse for successful NRTK. These cases should be informed to user by the network manager.

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