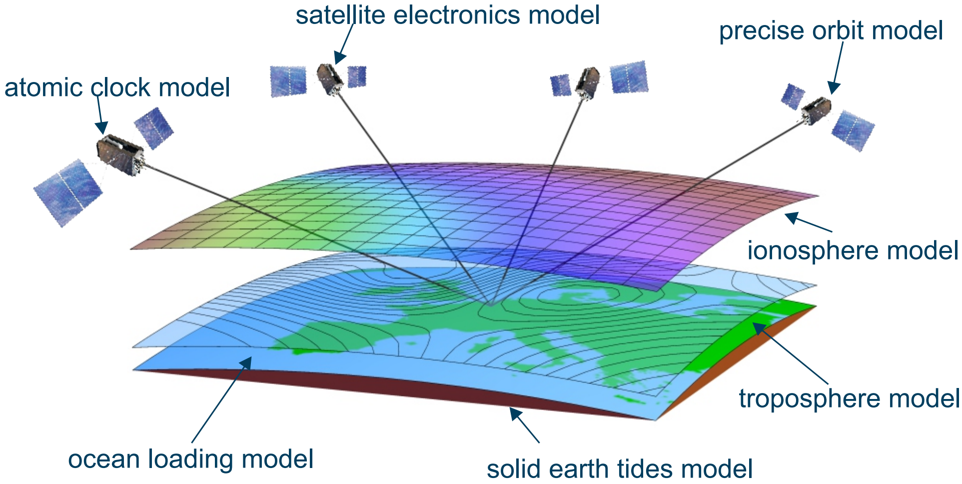
Geo++® SSR

For Network-RTK, PPP and PPP-RTK

State-Space-Modelling



GNSS signal errors are introduced by several sources, including satellite orbit and clock errors, biases as well as ionospheric and troposheric effects. In conventional RTK or Network-RTK systems, the lump sum of these effects is observed by the reference stations and provided to the rover as range corrections for each supported combination of station, satellite, frequency and signal. Systems using this Observation Space Representation (OSR) do not require advanced computational techniques and are widely implemented. However, they are unable to make use of the different stochastic properties of the underlying physical effects. In State-Space-Modelling (SSM) all relevant physical effects are represented by a mathematical model with parameters that are estimated in real time using the network observations. Knowledge about the temporal and spatial behavior of these effects allows for integration and optimal utilization of the information given by independent observations. The State-Space-Model can not only be used to calculate optimized OSR-RTK-corrections for conventional rovers, but also to provide the state vector itself to State-Space-Representation (SSR) rovers. Geo++ GNSMART (Global Navigation State Monitoring And Representation Technique) exploits these possibilities of State Space Modelling. The advantages of SSM for conventional Network-RTK as well as the advantages of a direct SSR approach are presented.

Minimized Bandwidth

Different error sources have different noise characteristics: while errors such as the satellite clock deviation have to be updated every few seconds to ensure cm accuracies, errors such as satellite orbits or athmospheric influences may vary on a longer timescale and only need to be updated with a lower rate. A Geo++ SSR based service is able to independently optimize the transmission rate and resolution for every error component - minimizing the total bandwidth required.

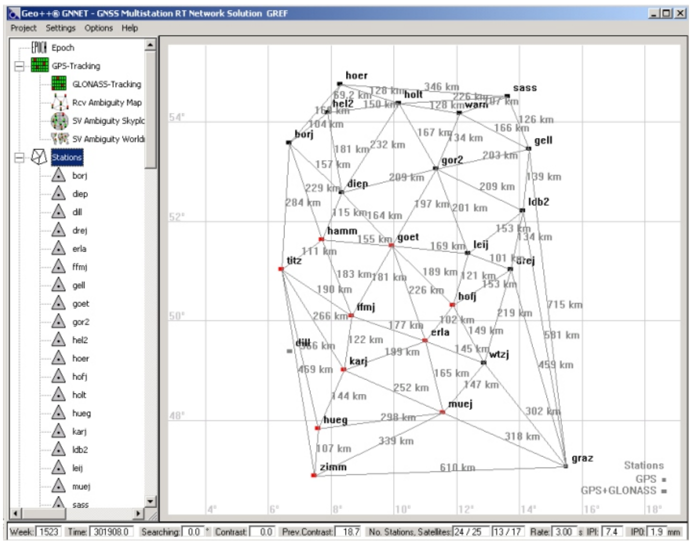
Single Frequency Operation

Contrary to conventional RTK, where the influence of the first order ionospheric effect is corrected by dual frequency measurements, an SSR based service allows the usage of single frequency rovers. Since the ionosphere is incorporated in the state space model, its influence can be predicted accurately. With this technique, accuracies of better than 30 cm (1σ) can be achieved. As no ambiguities have to be solved, this accuracy can be obtained within a single epoch using state of the art receivers. The robustness of this technique together with the low price of single frequency receivers allows for mass marked applications based on Geo++ SSR.

Low Infrastructure Requirements

Improved modelling of the spatial behavior of the physical effects disturbing GNSS signals enables better error estimation between reference stations. This allows for an increased reference station distance of up to 200 km for RTK applications compared to 50-70 km in conventional Network-RTK systems.

An additional advantage of Geo++ SSM networks is that different GNSS systems can be consolidated. Reference stations facilitating only parts of the available GNSS signals can still contribute fully to the atmospheric modelling. Only a small subset of the reference stations have to be able to track a specific signal to estimate the satellite signal specific state parameters.



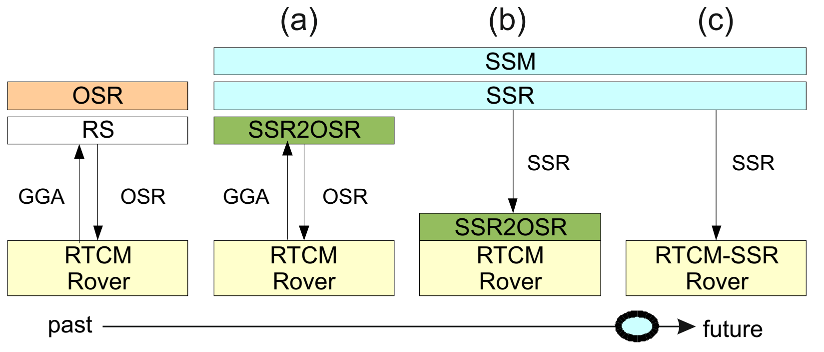
Example Network: 25 BKG GREF stations are used to generate SSR and provide RTK corrections for the area of Germany.

Broadcast Capability

In most OSR solutions, the user has to transmit his approximate position to the provider in advance. Subsequently he receives OSR corrections valid for this position. This requires a duplex data connection between user and provider.
The SSR state vector, however, is valid for the entire service area. Therefore, in SSR schemes, no user input is required to provide the correction data and a simplex data connection from the provider to the user is sufficient.
Together with the low bandwidth required, SSR is the ideal representation for broadcast services including satellite based augmentation systems.
This is why Geo++ SSR technology has been chosen to be transmitted on the L6 channel of the Japanese Quasi-Zenith Satellite System (QZSS). This Centimeter Level Augmentation Signal (CLAS) is planned to provide cm level accuracy within seconds in the area of Japan commencing 2018.

From OSR to SSR

To operate legacy rovers that do not support SSR in an SSM based network, it is necessary to convert the SSR information to OSR. In current Geo++ GNSMART networks this is done on the provider‘s server (a). To make use of the low bandwidth and the broadcast ability of SSR, this conversion can also be performed at the rover site (b). With ongoing standardization and rover development, more and more rovers are inherently capable of SSR, making OSR obsolete (c).



Scalable Services

Geo++ SSR offers network providers a high level of flexibility. Networks may be adjusted precisely to the demands of the final customer. As an example a network may consist of regions with inhomogeneous reference station density - generating highest accuracies where required and low costs where intermediate performance can be accepted. The provider may choose to only transmit a subset of the SSM state vector, valid for a specified area, accuracy or task. This allows for a high versatility in product definitions.

	phase based PPP	code based PPP	PPP-RTK
satellite orbits	✓	✓	✓
satellite clocks	✓	✓	✓
satellite biases	✓	✓	✓
ionosphere	✓	✓	✓
troposphere	✗	✓	✓
L0 ambiguities	✓	✗	✓
L1/L2 ambiguities	✗	✗	✓

✓: provided, ✓: corrected by rover,
✗: estimated by rover, ✗: not possible

Subsets of the SSR-Vector provided for different SSR solutions.

Comparison of Common Representation Techniques

	OSR Observation State Representation				SSR State Space Representation		
	RTK	Network - RTK			Phase based PPP	Code based PPP	PPP - RTK
	RS	FKP	MAC	VRS/PRS			
Service classification (1)	OSR-CS2	OSR-CS2			SSR-CQ2	SSR-DS1	SSR-CS2
Broadcast possible	✓	✓	✓	✗	✓	✓	✓
Accuracy	~ cm	~ cm	~ cm	~ cm	< dm	~ 3 dm	< cm
Time required (2)	< 5 s	< 5 s	< 5 s	< 5 s	~ 20 min	< 1 s	< 5 s - 1 min (3)
Service area	local	regional			global	global / regional	global/ regional
Single frequency	✗	✗	✗	✗	✗	✓	✗
Required bandwidth	medium	medium	high	medium	low	low	low-medium

(1): **CQ2: C**entimeter accuracy in **Q**uarters of hours using **2** frequencies
DS1: Decimeter accuracy in **S**econds using **1** frequency
CS2: Centimeter accuracy in **S**econds using **2** frequencies

(2): no multipath (3): depends on update rate

Geo++ GNSMART can support all representation techniques mentioned!