SSR Technology for
Scalable Real-Time GNSS Applications

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Abstract

SSR Technology for scalable Real-Time GNSS Applications

The use of State Space Representation (SSR) is the most convincing and acknowledged GNSS augmentation technology to cope with the increase of new signals and new constellations in the future.

The synergy of Precise Point Positioning and SSR for RTK networking has been widely addressed. Scalable SSR applications have the goal to support both, global but also regional or local applications.

Concepts are presented working out the benefits of SSR and the consequential splitting of GNSS error components over messages. An essential task is the handling of signal biases in multi-signal multi-constellation applications.

The general approach proposed for SSR is summarized. Finally the presentation will give a short status of the international standardization efforts.
Outline

- GNSS Augmentation in SSR and OSR Domain
- Scalable Services with SSR
- SSR Standardization
- Summary/Outlook
GNSS Augmentation in SSR and OSR Domain

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GNSS Augmentation in the OSR Domain

Recall, the simple case of real-time differential GNSS corrections assuming high correlation of GNSS error components:

- use known reference station coordinates
- determine lump-sum of GNSS errors

The range measurements of a user's GNSS positioning are improved by applying GNSS range correction as measured by a nearby reference station.

Since the observations of the reference stations are used directly, this approach is classified as an observation space representation (OSR) technique.

Examples include (network)-RTK and DGPS.
A network of reference stations is used to decorrelate the different **GNSS error components**: 

- satellite clocks  
- satellite orbits  
- satellite signal biases  
- ionospheric delay/advance  
- tropospheric delay  

With this, users can **generate GNSS corrections** valid for their own position.

Additionally, statistical **accuracy information** can be provided to support the user's GNSS positioning algorithm.

Since the state of the GNSS error components is determined, this approach is termed as a **state space representation (SSR)** technique.

Examples include SBAS, PPP and PPP-RTK.
- GNSS Augmentation in SSR and OSR Domain
- **Scalable Services with SSR**
  - SSR Standardization
  - Summary/Outlook
Scalable Services – Communication Link

With OSR,

- the GNSS corrections are often realized with a so-called pseudo (PRS) or virtual reference stations (VRS).
- This requires **one duplex data channel per user**.

With SSR,

- the GNSS corrections are **broadcast** with **one data stream for all users**.
- This enables the use of **simplex communication** media (satellites, digital radio, ...) alternatively to the Internet.
Minimizing Bandwidth – Scaling SSR in Time Domain

Analyzing the individual characteristics of the GNSS error components reveals:

- Due to short-term fluctuations of satellite clocks, cm level positioning requires correction data updates approximately every 10 seconds.
- Other GNSS errors components change at lower rates.
- Adjusting individual update rates of SSR components can drastically reduce the bandwidth requirement while keeping the quality the same.
Scalable Services – Scaling Signals

SSR inherently supports the variety of GNSS, frequencies and signals:

- Additional GNSS or signals can be added to existing services seamlessly.
- There is no need for the same reference station hardware to support all GNSS and signals.
- The same SSR service can be used by
  - mass market single frequency users
  - and high precision multi-GNSS multi-frequency users.
Scalable Services – Scaling Service Areas

With SSR,

- **various quality levels** of GNSS positioning
- **for different regions**
- can be represented with a **single data stream**.

For example, a GNSS correction service

- could supply a **region with high reference station density** with an **RTK quality** service,
- while **all adjacent regions** are provided with **PPP quality**.
Scalable Services – Backward Compatibility

- **Legacy GNSS positioning** can be supported via **SSR2OSR conversion** either on the server or rover side.

- **Optimal performance** will be reached once the **SSR corrections** with accompanying accuracy information are **directly incorporated** in the positioning engine.
- GNSS Augmentation in SSR and OSR Domain
- Scalable Services with SSR
- **SSR Standardization**
- Summary/Outlook
SSR Standardization by the RTCM

Since 2007 the SSR working group of the Radio Technical Commission for Maritime Services (RTCM) Special Committee 104 is developing a standard message format for SSR messages.

**Goals** of RTCM-SSR development are

- that messages are self-contained, flexible and non-restricting
- and serve scalable GNSS applications with different accuracy requirements.

**Status** of standardization

- is slowed down, because of missing agreement on interoperability testing (new WG established).
- Consensus is expected after testing of a complete set of SSR messages.

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User Range Accuracy

+: RTCM-SSR first published in „RTCM STANDARD 10403.1 with Amendments 1-5“, July 1, 2011
*: for GPS and GLONASS only, messages are proposed for Galileo, QZSS, BDS & SBAS
SSR Standardization - Satellite Biases

Every transmitted GNSS signal component experiences a *specific signal delay* (bias) in every satellite hardware/software.

**Satellite Biases** are defined

- as “absolute biases“ (may contain remaining/average/reference receiver biases),
- for satellite **code and phase signals**, and
- which inherently supports relative biases.

It is expected, that all software dependent bias concepts can be mapped to the RTCM-SSR approach.

**Example**

- error components:
  - satellite clock error $dt$ and
  - code biases $B^c_i$ and phase biases $B^p_i$
- combined clock and signal signal delay error at satellite antenna:

\[
\begin{align*}
\text{dC1C} &= dt + BC1C \\
\text{dC2W} &= dt + BC2W \\
\text{dC2C} &= dt + BC2C \\
\text{dC5i} &= dt + BC5I \\
\text{dL1W} &= dt + BL1W \\
\text{dL2W} &= dt + BL2W \\
\text{dL2C} &= dt + BL2C \\
\text{dL5i} &= dt + BL5I
\end{align*}
\]

Linear dependency between clock and bias terms

$==> \text{only 7 (n_signal -1) independent parameters}$
The multi-stage model

- utilizes different messages for the same GNSS error component.
- constituents from different messages are added, which adds accuracy.
- is required for e.g. spatial variation of atmospheric parameters or optimal data compression
- and allows different service applications/accuracies.

An example is the ionosphere, which consists of one or more constituents provided as

- an initial Vertical TEC spherical harmonics model
- and/or slant TEC components
- and/or a gridded TEC component.
- GNSS Augmentation in SSR and OSR Domain
- Scalable Services with SSR
- SSR Standardization

- **Summary/Outlook**
SSR technology provides

- broadcast GNSS corrections
- minimized bandwidth
- scalable GNSS services concerning
  - variety of GNSS and signals
  - positioning accuracy
  - service areas
- backward compatibility to GNSS applications

which are essential benefits for scalable real-time GNSS applications
Summary/Outlook (2)

- State Space Representation (SSR) is most convincing GNSS augmentation technology to cope with the increase of new signals and new constellations.

- SSR standardization is challenging.

- SSR can replace OSR techniques for all types of GNSS positioning applications with better performance and less costs.
SSR – Fusion of GNSS Augmentations

GNSS augmentation with **SSR** combines the **accuracy of RTK** with the **broadcast** and low bandwidth benefits of **PPP**.

It is backward compatible to all legacy augmentation methods and can be **universally adopted to any reference station network**, no matter if

- global or regional
- high density or low density
- single, double or triple frequency.