PPP with Ambiguity Resolution (AR) using RTCM-SSR

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IGS Workshop, 23.-27.06.2014, Pasadena, CA, USA

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Abstract

The RTCM SC104 is developing a standard format to disseminate GNSS state space information. The RTCM-SSR (State Space Representation) format will support a variety of applications at different accuracy levels. Different SSR messages are evolved in basically three stages.

Stage 1 enables code-based PPP applications and consists of messages to transport satellite orbit corrections, satellite clock corrections and satellite signal code biases.

The next milestone (stage 2) is approaching standardization and consists of messages for vertical ionospheric total electron contents (VTEC) to enable single frequency code based PPP as well as messages for satellite signal phase biases to enable phase based PPP and ambiguity resolution.

Stage 3 shall concentrate on the development of slant ionospheric total electron content messages (STEC) as well as tropospheric delay messages to allow PPP-RTK, i.e. centimeter accuracy through ambiguity resolution within seconds of observation time.

The presentation discusses the overall RTCM-SSR concepts and development strategies as well as the current status and schedule.

Special focus will be on the consistency of SSR parameters and processing with respect to satellite signal code and phase biases and its relation to ambiguity resolution.

Outline

- RTCM SC104 SSR Working Group
- Strategy / Concepts for RTCM-SSR Development
- Satellite Code and Phase Biases
- Carrier Phase Ambiguity Resolution
- RTCM SSR Working Group - Status
- Summary/Outlook

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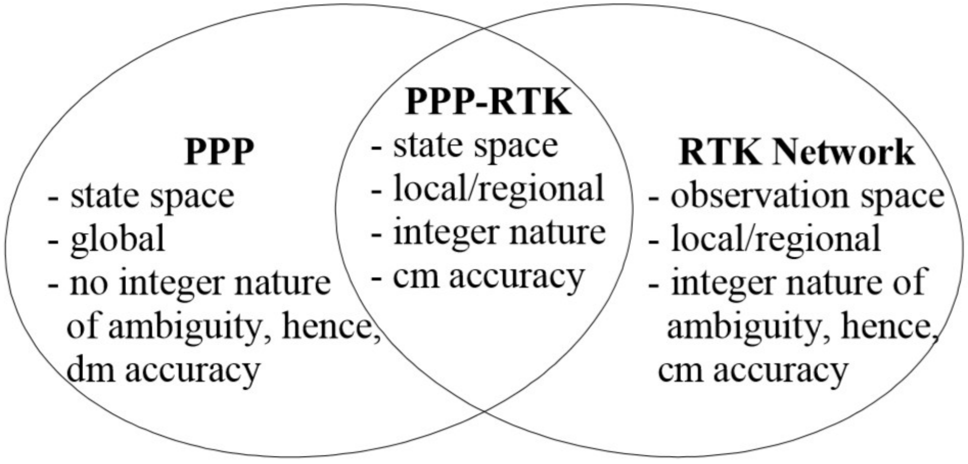
RTCM SC104 – SSR Working Group

- RTCM SC104 – SSR Working Group established in 2007
  - about 10+ active members
  - about 30+ members in total

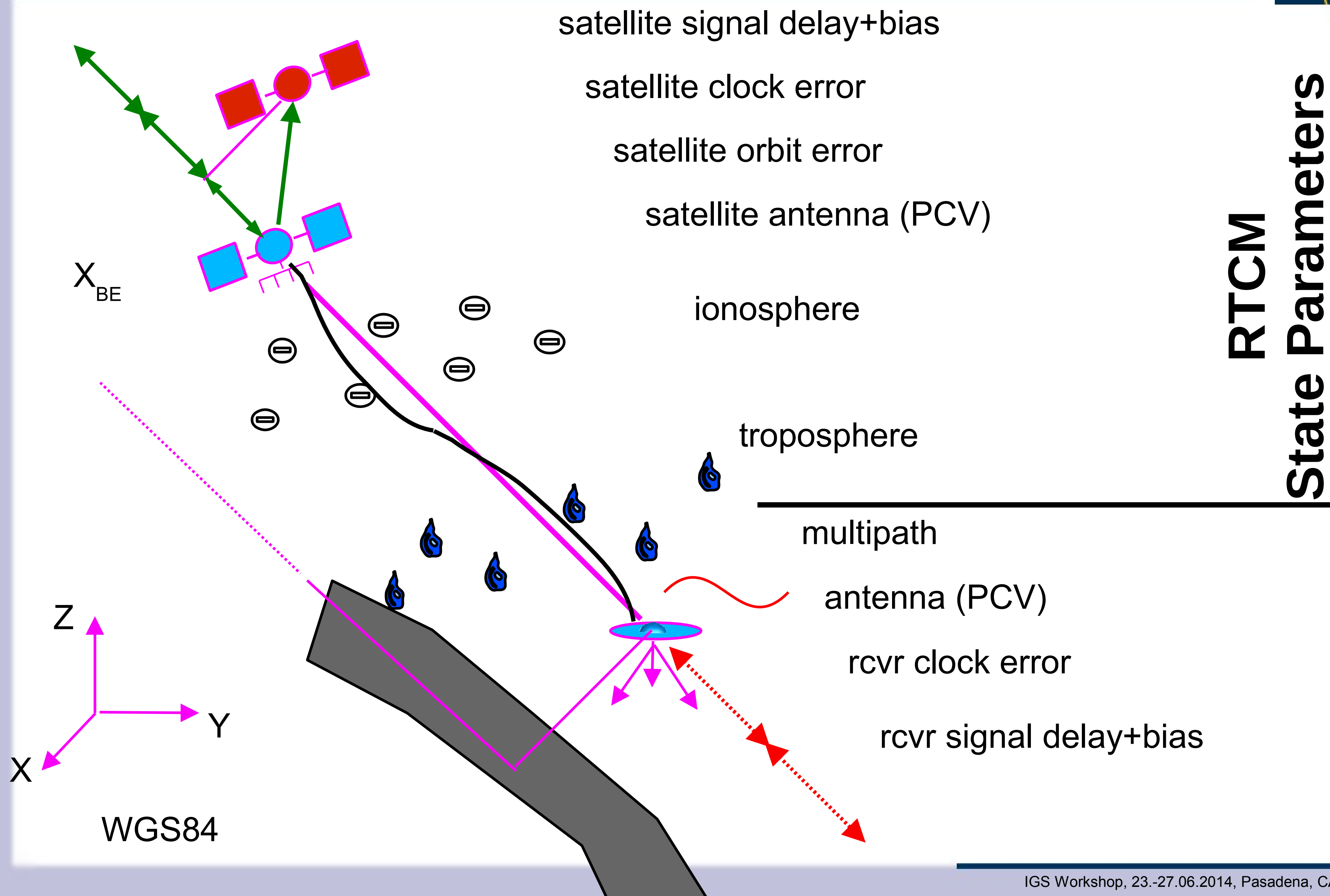
- **primary goal**
  - development of RTCM-SSR messages
    to exchange information about
    GNSS error states (SSR State Space Representation)
    up to **precise positioning** applications
    including RTK

    Synthesis of
    PPP and RTK Networking*



*Wübbena et.al (2005). PPP-RTK: Precise Point Positioning Using State-Space Representation in RTK Networks.ION GNSS 2005, September 13-16, Long Beach, California.

Major GNSS Error Sources & RTCM State Parameters



RTCM SSR Working Group

proposed work plan consists of development of
RTCM-SSR Messages in **three major stages**/steps:

- Stage 1
  satellite *orbit*, satellite *clock* and satellite *code bias* messages
  to enable **code-based real-time PPP for dual frequency** receivers:
  DF-RT-PPP
- Stage 2
  vertical TEC (*VTEC*) ionospheric message
  to enable **code-based RT-PPP for single frequency** receivers:
  SF-RT-PPP,
  satellite *phase bias* messages
  to enable **phase-based RT-PPP**.
- Stage 3
  ionospheric slant TEC (*STEC*) and *tropo*spheric messages
  to enable **RTK-PPP**.

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Strategy / Concepts for RTCM-SSR Development

- RTCM-SSR shall be a **self-contained** format as far as possible

  i.e. all necessary information for consistent processing shall be contained in the RTCM-SSR stream or shall be specified inf the standard document; the need for external information should be avoided
  - counter example: satellite PCV (tbd)

- the definition of RTCM-SSR contents **shall not limit/restrict** the generation of SSR streams; **no use of particular generation models or approaches**
  - example: conventional approaches with dynamic orbit modeling (IGS) as well as approaches with kinematic orbit modeling shall be supported

- **international conventions for** observation **modeling and/or corrections** shall be applied **as far as necessary** and as long as they are well defined and documented and freely usable
  - example: IERS convention

- do not prevent new ideas, models or approaches!

Strategy / Concepts for RTCM-SSR Development

- the standard shall allow in a flexible way
  different update rates for different state parameters

  Different error states possess different variability with time.
  Slowly changing states need lower update rates as highly variable states.
  This is the key characteristic that allows minimization of stream bandwidth.

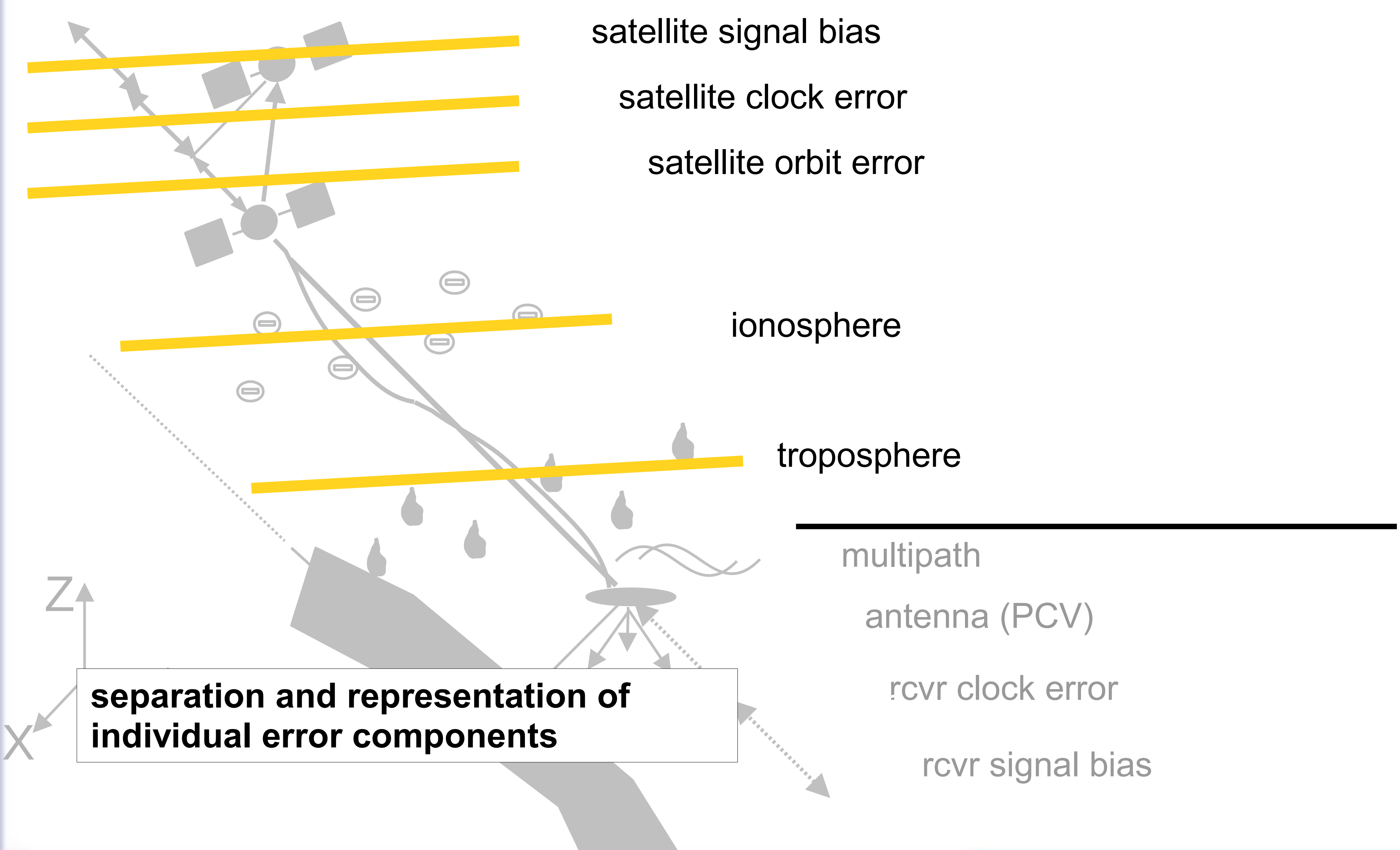
- **self-consistency** of RTSM-SSR streams must be achieved

- **consistent processing** of SSR stream contents must be ensured

  Consistency is one of the major requirements in order to achieve the desired performance. Consistency of algorithms and computations for reference models must be assured as well as consistency of state parameter sets.

- the RTCM-SSR standard shall support
  scalable global, continental, regional and/or local applications

State Space Representation – GNSS Error States



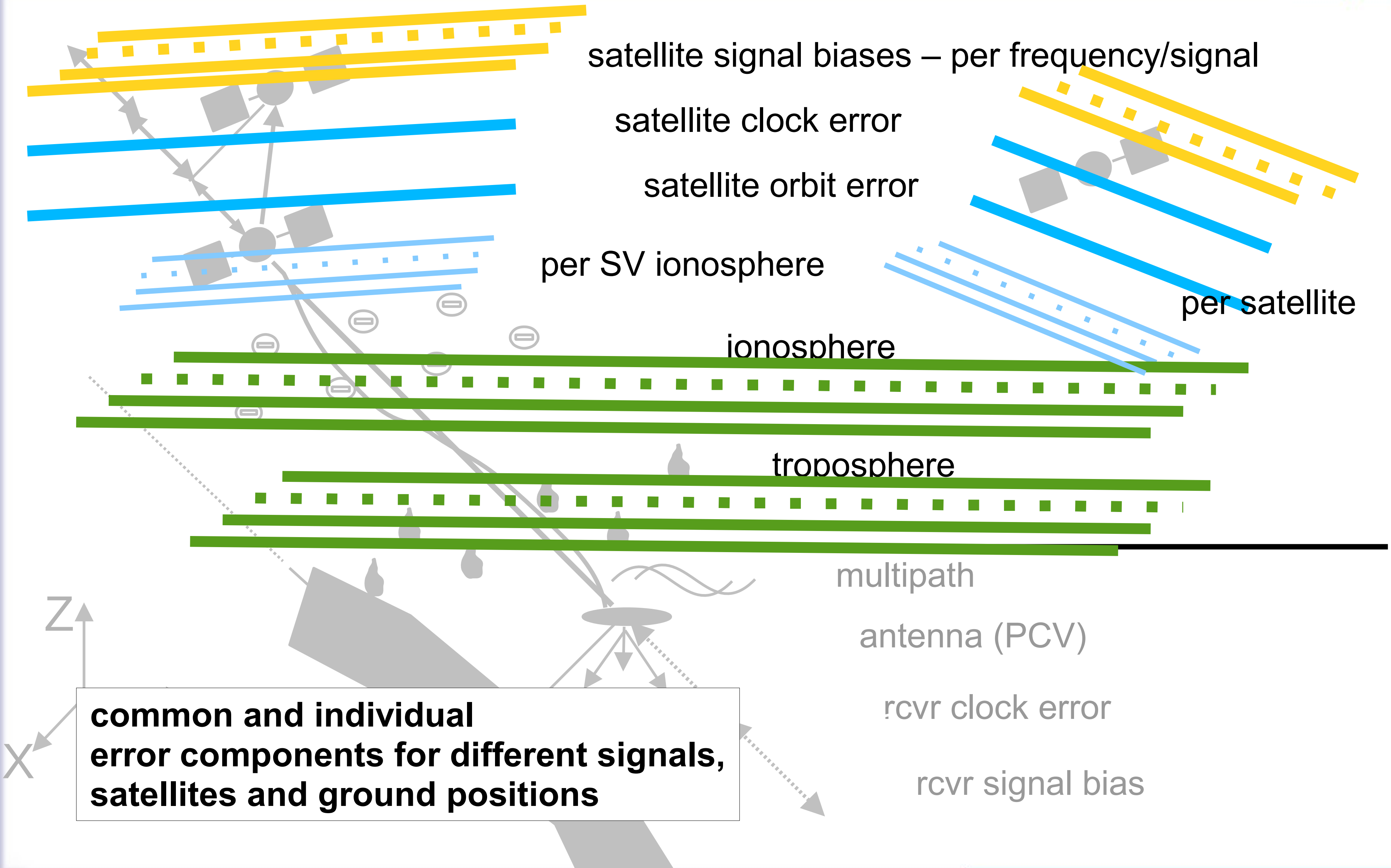
separation and representation of individual error components

Strategy / Concepts for RTCM-SSR Development

- **multiple stage models**
  - different messages for same state constituent
  - different **messages are added**
  - added messages add accuracy
  - required for RTCM-SSR development
    (e.g. spatial variation of atmospheric parameters)
  - **allows for different applications/accuracies**

- **examples**
  - satellite clock
    - initial component clock polynomial
    - optional component high rate clock
  - ionosphere
    - initial model Vertical TEC spherical harmonics
    - additional component slant TEC

SSR – Spatial Variations of GNSS Atmospheric States



common and individual error components for different signals, satellites and ground positions

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Satellite Code and Phase Biases

- **every transmitted GNSS signa**l component experiences **a specific signal delay** (bias) in satellite HW/SW
- applies to satellite **code and phase signals**

- example:
  - GPS dual frequency observations:
    code (**P1, P2**) and **carrier** (**L1, L2**)
  - error components:
    satellite clock error dt and
    code biases BPi and **phase biases BL**i
  - combined clock and signal signal delay error at satellite antenna:

dP1	=	dt	+ BP1			
dP2	=	dt		+ BP2		
dL1	=	dt			+ BL1	
dL2	=	dt				+ BL2

linear dependency between clock and bias terms
==> **only** 4 (**n_signal -1**) **independent parameters**

Satellite Code and Phase Biases

- **no** specific **reference bias/signal used** in RTCM-SSR, which allows **maximum flexibility** for service providers

- example
  - complete support of **reference bias/signal** like ionospheric free linear combination of P1, P2 (**GPS/IGS**)
  - **BR** defined to be bias-free gives biased clock and “differential” signal biases:

$$
\begin{aligned}
dP1 &= (dt + BR) + (BP1-BR) \\
dP2 &= (dt + BR) + (BP2-BR) \\
dL1 &= (dt + BR) + (BL1-BR) \\
dL2 &= (dt + BR) + (BL2-BR)
\end{aligned}
$$

or

$$
\begin{aligned}
dP1 &= dt' + BP1' \\
dP2 &= dt' + BP2' \\
dL1 &= dt' + BL1' \\
dL2 &= dt' + BL2'
\end{aligned}
$$

- **individual signal** component **(code or carrier)** can be utilized, if corresponding and **consistent bias** is transmitted

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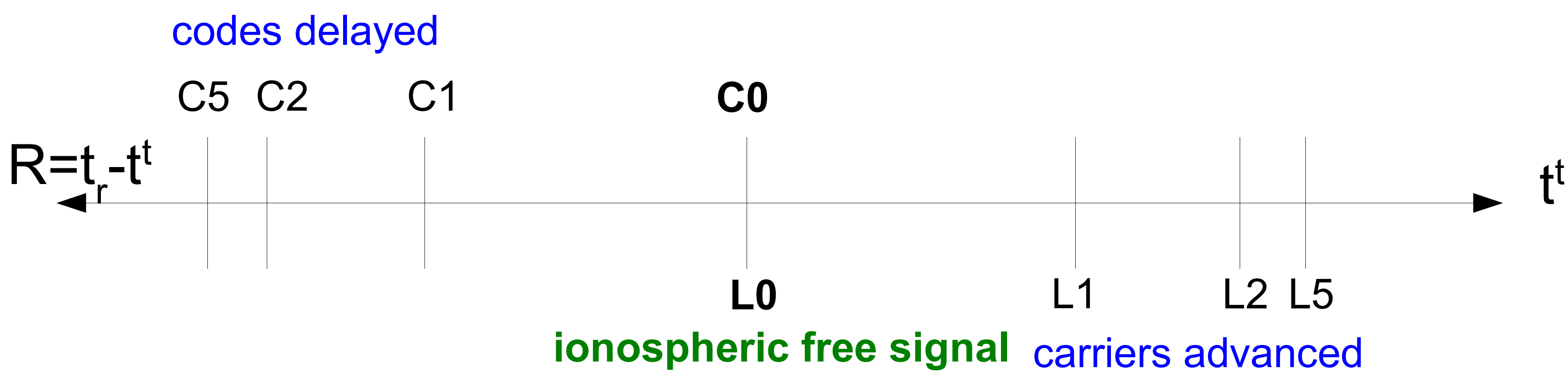
Ambiguity Resolution

- RTK (“centimeters in seconds”)
  requires resolution of carrier phase ambiguities
- different techniques have been developed in the past
  - GFAR – **G**eometry **F**ree **AR**
    - linear combinations of different code and carrier signals are used to determine ambiguities
    - often used: **Melbourne-Wübbena** - **MW**
      - combines carrier wide lane and code “narrow lane” to resolve wide lane ambiguity
  - GBAR – **G**eometry **B**ased **AR**
    - utilizes redundant satellites to find the optimal integer ambiguity vector
    - often used: **Lambda** method
      (Teunissen (1993) Technical University of Delft)
  - **combinations of GFAR and GBAR**

First Order Ionospheric Effect on Signal Components

- signal components received at the same time have different „apparent“ transmission times
  - higher order ionospheric and multipath effects ignored
  - **satellite code and phase biases are important**

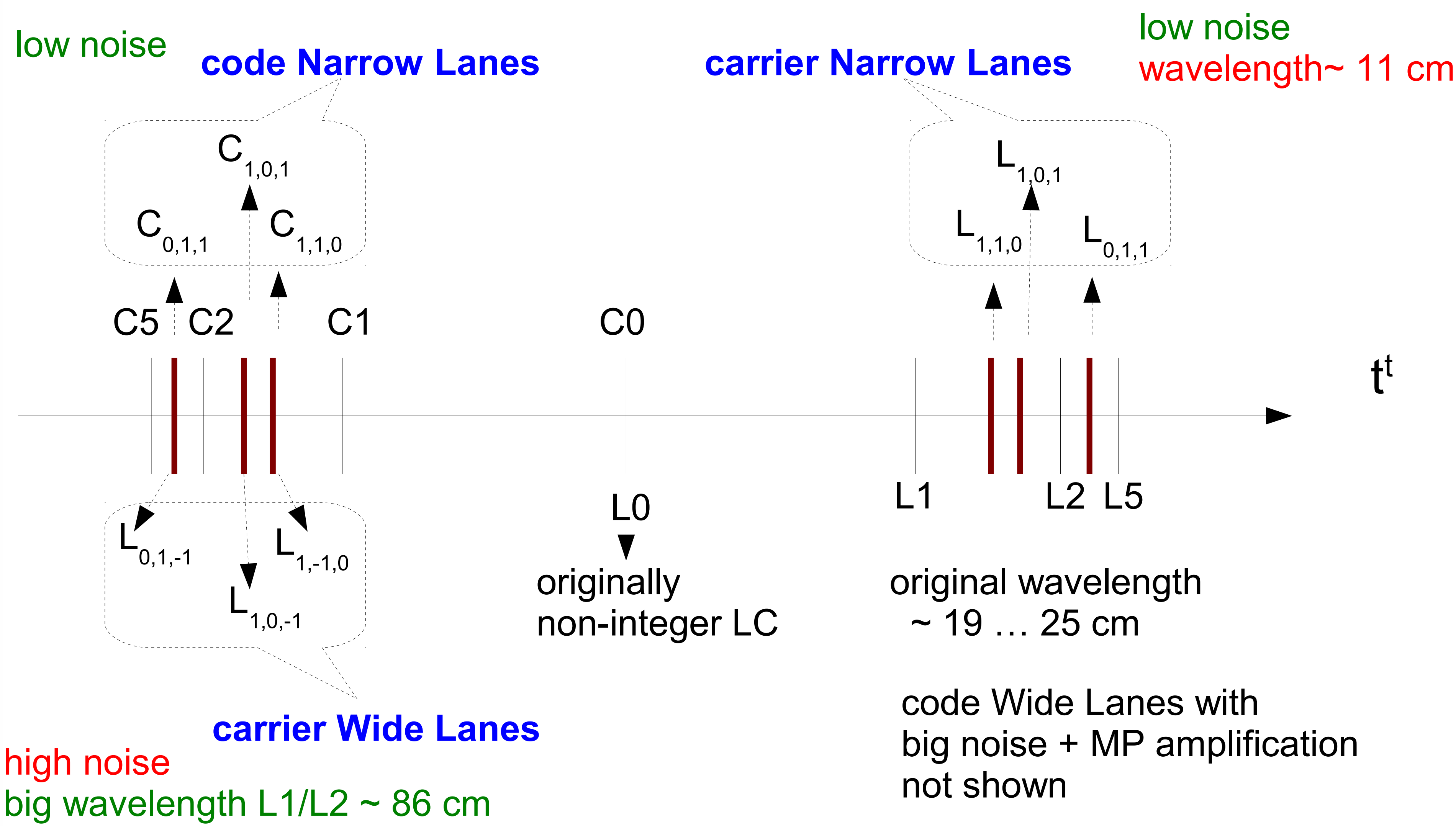
apparent GPS Signal transmission times (first order iono effect):



- C1, C2, C5 – code epochs on L1, L2, L5 carrier
- L1, L2, L5 – carrier phase epochs
- C0, L0 – ionospheric free (first order) linear combination for code (C0) and carrier (L0)
- **RTK requires ambiguity free L0 or elimination of ionospheric effect**

Ambiguity Resolution - Narrow and Wide Lanes

apparent signal transmission times:



Ambiguity Resolution

- ambiguity resolution
  - **requires consistent** satellite phase and code **biases**
  - **increasing complexity** with variety of signals and GNSS

- RTCM-SSR biases support ambiguity resolution condition, furthermore
  - flexible, serves different approaches and strategies

- indication of **partial services** required in RTCM-SSR
- services may be based on
  - ionospheric free linear combination
  - on float/fixed ambiguities on reference stations
  - particular characteristic/consistency of RTCM-SSR

Ambiguity Resolution

- basic **content of RTCM-SSR** satellite **phase signals** and **properties to indicate partial services**
  - per GNSS
    - satellite **bias-free ionospheric observable** indicator (dispersive bias consistency indicator)
    - satellite **bias free code/phase observable** indicator (Melbourne-Wübbena - MW consistency indicator)
  - per satellite
    - **yaw** angle and yaw rate
  - per GNSS signal and tracking mode
    - satellite **bias free phase with integer nature** indicators (signal integer indicator, signal wide lane integer indicator and signal discontinuity counter)
    - **phase bias**

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RTCM SSR Working Group - Status

- Stage 1 DF-RT-PPP
  standardized since Mai 2011: GPS GLONASS
  proposed/interoperability testing: Galileo QZSS SBAS BDS

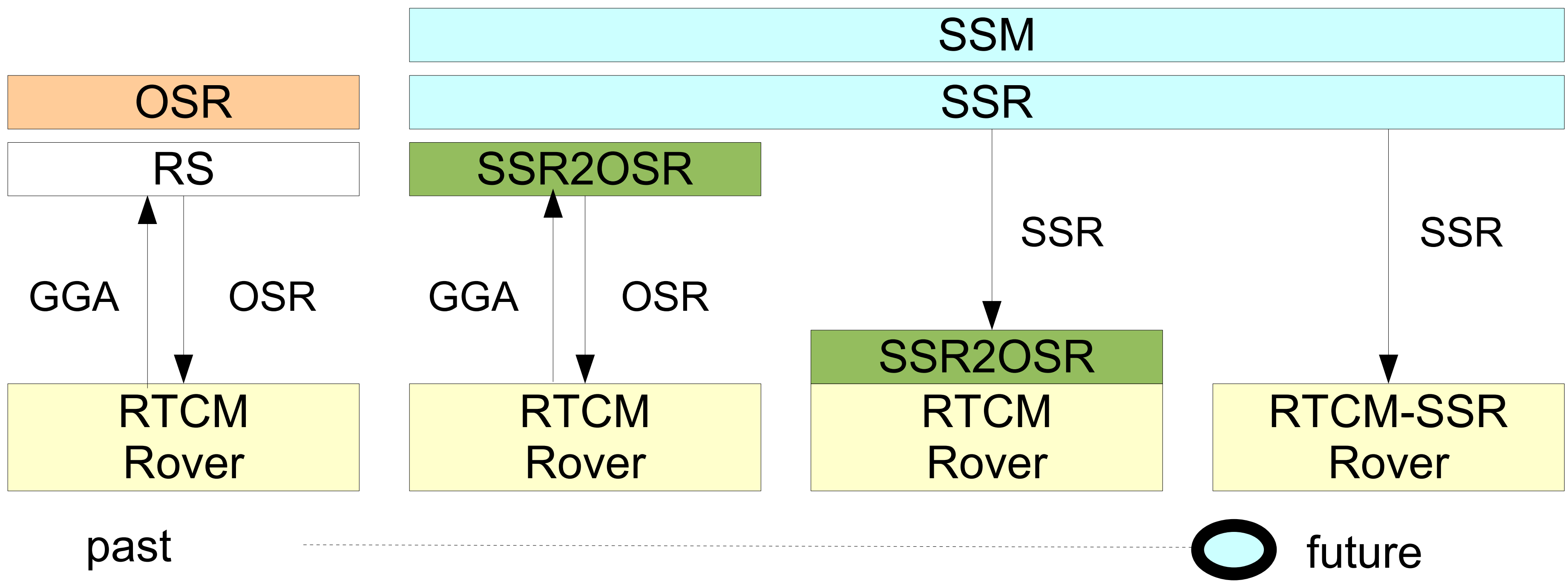
- Stage 2 SF-RT-PPP/RT-PPP
  proposed/interoperability testing: satellite phase bias messages
  vertical TEC (VTEC) message
  (spherical harmonics)

- Stage 3 RTK-PPP
  initial concepts slant TEC (STEC) messages
  under consideration troposphere

- availability of new proposed messages depends on some technical issues, interoperability tests and on progress in RTCM
- need for an additional Stage 4 (“first define contents”)

  - **Stage 4 Compression**
    compression of messages/reduce of bandwidth

SSR Application for GNSS Positioning



SSM State Space Monitoring
OSR observation space representation
SSR state space representation
RS reference station
GGA NMEA position messsage

- SSM/SSR concept operationally applied with Geo++ GNSMART

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Summary/Outlook

- SSR standardization is challenging
- RTCM-SSR messages shall
  - be self-contained, flexible and non restricting
  - serve scalable applications and accuracy requirements
- ambiguity resolution for PPP supported by
  proposed satellite phase biases support ambiguity resolution
- SSR standardization requires time; next steps are
  - interoperability testing of proposed RTCM-SSR messages
  - start on Stage 3 RTCM-SSR development
- SSR can replace OSR techniques for all types of GNSS positioning applications with better performance and less costs
- need for demonstration of SSR performance to convince markets

Standardized RTCM SSR Messages

- Stage 1 for GPS and GLONASS

Message Type	Message Name
1057	SSR **GPS Orbit** Correction
1058	SSR **GPS Clock** Correction
1059	SSR **GPS Code Bias**
1060	SSR GPS Combined Orbit and Clock Corrections
1061	SSR GPS URA
1062	SSR GPS High Rate Clock Correction

1063	SSR **GLONASS Orbit** Correction
1064	SSR **GLONASS Clock** Correction
1065	SSR **GLONASS Code Bias**
1066	SSR GLONASS Combined Orbit and Clock Correction
1067	SSR GLONASS URA
1068	SSR GLONASS High Rate Clock Correction

Proposed RTCM SSR Messages (May 2012)

- Stage 1 RTCM SSR Galileo QZSS

Message Type	Message Name
1240	SSR **Galileo Orbit** Correction
1241	SSR **Galileo Clock** Correction
1242	SSR **Galileo Code Bias**
1243	SSR **Galileo** Combined Orbit and Clock Corrections
1244	SSR **Galileo** URA
1245	SSR **Galileo** High Rate Clock Correction

1246	SSR **QZSS Orbit** Correction
1247	SSR **QZSS Clock** Correction
1248	SSR **QZSS Code Bias**
1249	SSR **QZSS** Combined Orbit and Clock Correction
1250	SSR **QZSS** URA
1251	SSR **QZSS** High Rate Clock Correction

Proposed RTCM SSR Messages (May 2012)

- Stage 1 RTCM SSR SBAS BDS

Message Type	Message Name
1252	SSR **SBAS Orbit** Correction
1253	SSR **SBAS Clock** Correction
1254	SSR **SBAS Code Bias**
1255	SSR **SBAS** Combined Orbit and Clock Corrections
1256	SSR **SBAS** URA
1257	SSR **SBAS** High Rate Clock Correction

1258	SSR **BDS Orbit** Correction
1259	SSR **BDS Clock** Correction
1260	SSR **BDS Code Bias**
1261	SSR **BDS** Combined Orbit and Clock Correction
1262	SSR **BDS** URA
1263	SSR **BDS** High Rate Clock Correction

Proposed RTCM SSR Messages (May 2012)

- Stage 2 RTCM SSR Satellite Phase Bias

Message Type	Message Name
1265	SSR Satellite **GPS** Phase Bias
1266	SSR Satellite **GLONASS** Phase Bias
1267	SSR Satellite **Galileo** Phase Bias
1268	SSR Satellite **QZSS** Phase Bias
1269	SSR Satellite **SBAS** Phase Bias
1270	SSR Satellite **BDS** Phase Bias

Proposed RTCM SSR Messages (May 2012)

- Stage 2 RTCM SSR VTEC

Message Type	Message Name
1264	SSR Ionosphere Spherical Harmonics