The 7th Meeting of International Committee on GNSS

--Working Group A

Research on GNSS Interoperable Parameters

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Background

- ***Interoperability*** refers to the ability of global and regional navigation satellite systems and augmentations and the services to be used together to provide better capabilities at the user level than would be achieved by relying solely on the open signals of one system.
- Multi-GNSS is able to achieve interoperability.
- **BUT**, existence of differences among GNSSs cause inconvenience to users.

Background

Thus, we need:

- Define the differences among GNSSs
- Study the parameters to represent these differences
- Process and transmit the parameters to users
- Make sure the users can depend on the parameters to improve services

Differences among GNSSs

Differences among GNSSs:

——**Constellation:** Satellite number, Types of satellite orbit, ect.

——**Signal:** Modulation, Center frequency, Received power, ect.

——**Message:** Massage structure, Data content, Data format, etc.

——**System time reference**

——**System coordinate reference**

These differences effect users on:

——Position ,Navigation and Timing

Differences among GNSSs

Positioning equation:

$$\sqrt{(x-x_i)^2+(y-y_i)^2+(z-z_i)^2}-c\cdot v_{T_b}=\tilde{\rho}_i+(\delta\rho_i)_{ion}+(\delta\rho_i)_{trop}-c\cdot v_{t_i^a}$$

the elements :

– –can be obtained from signals or messages of different system;

– –have different format and precision.

Elements	Differences				Parameter	Differences			
	From Signal	From Message	Format	Precision		From Signal	From Message	Format	Precision
(x_i,y_i,z_i)		√	√	√	$\tilde{\rho}_i$	√	√	√	√
$(\delta\rho_i)_{ion}$	√	√	√	√	$v_{t_i^a}$		√		√

GNSS interoperable parameters

Differences	Items
Signal	User-Received Signal Level, Modulation Error, Correlation Characteristics, Phase Coherence, TGD
Ephemeris	Orbit offset, GNSS reference bias
Onboard Clock	Clock offset, GNSS Time Bias
Propagation	Ionosphere
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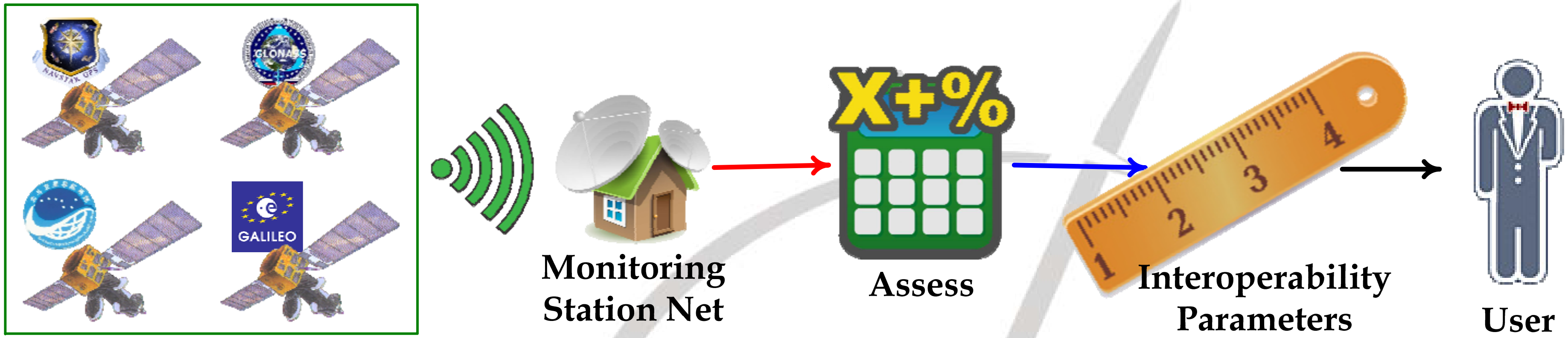
GNSS interoperable parameters

GNSS Interoperability



In order to provide better service for users:

——utilize specific method to monitor interoperable parameters;

——calculate parameters in a common time reference and coordinate reference frame;

——broadcast parameters to users;

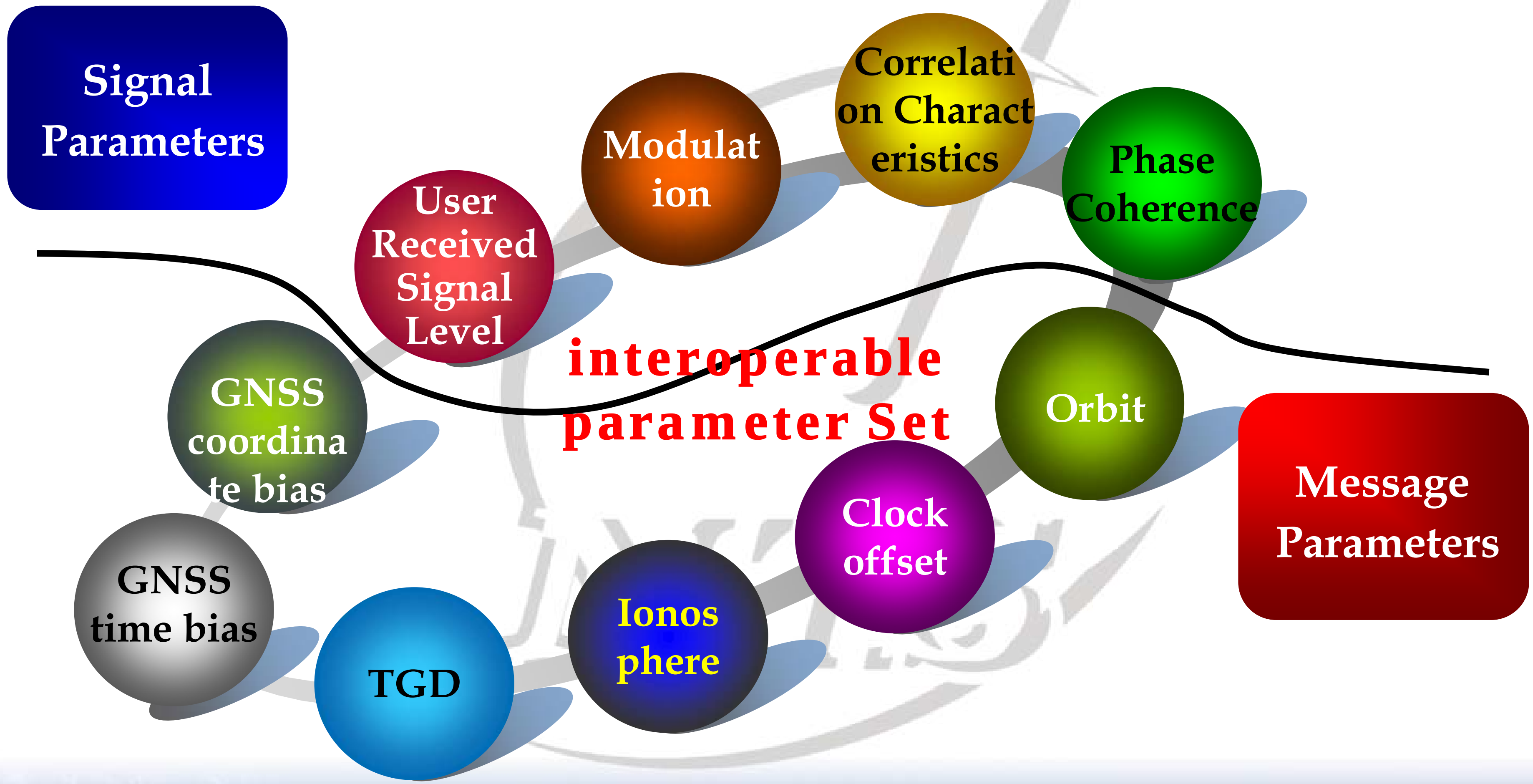
——take parameters to eliminate adverse effect of the GNSS differences.

GNSS Interoperability

Without interoperable parameters

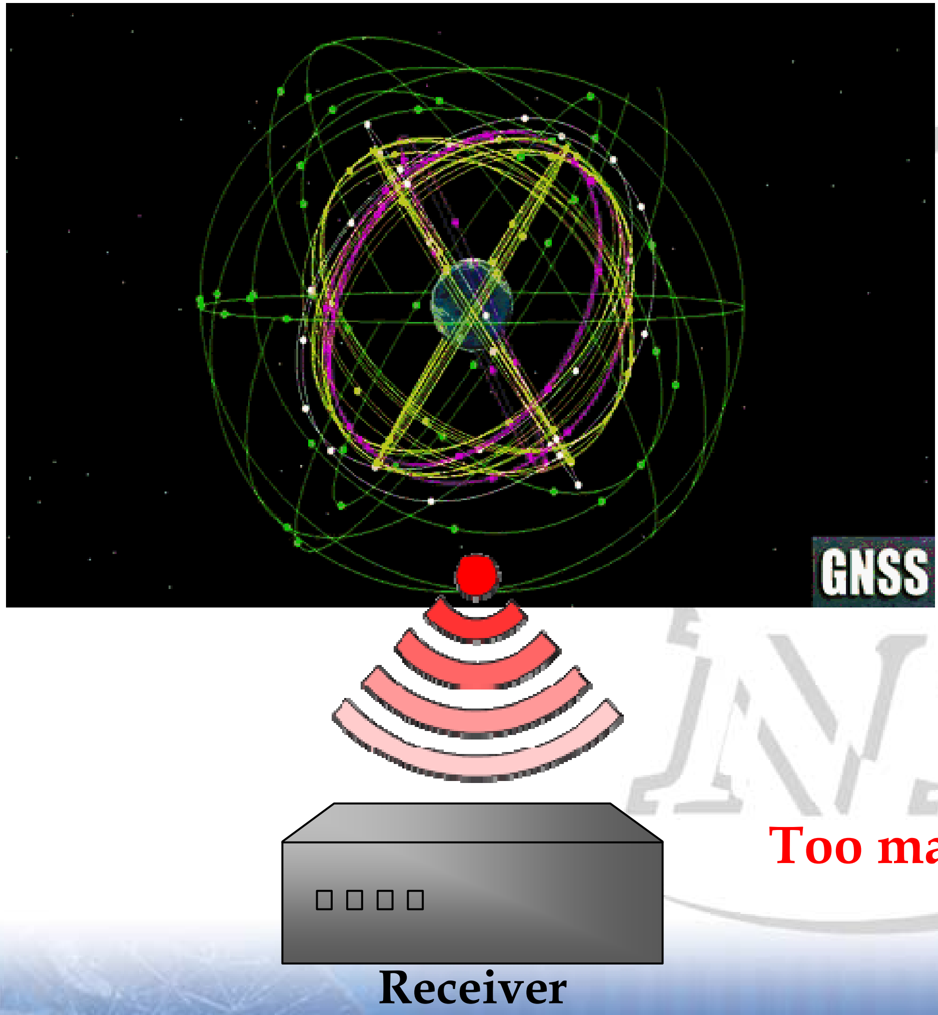
GNSS interoperable parameters

Divide these interoperable parameters into two sub-sets:



GNSS interoperable parameters

Signal Parameters



Provide users interoperable parameters in signal level:

——ability to chose a high quality signal in receiving process

——reduce the first positioning duration and decrease the complexity of receiver

Too many signals!

GNSS interoperable parameters

User Received Signal Level

Definition: The signal power when it arrives at the ground station.

Detection: Use ground monitoring receiver to monitor the signal power and its variation range.

Modulation

Definition: The error which was produced in the modulation and transmission, including: phase modulation error and amplitude modulation error.

Phase modulation error: The differences between the real phase in each channel and the ideal phase of the signal.

Amplitude modulation error: The differences between the real amplitude in each branch and the ideal amplitude of the signal

Detection : Compare the received signal to designed signal.

GNSS interoperable parameters

Correlation Characteristics

Definition: Outputs of correlation peak amplitude and correlation curve characteristics after the operation of signal correlation.

Correlation loss: Power difference between the actually received signal and the ideal signal in the designed bandwidth of the signal.

Correlation curve: The curve obtained through correlation calculation between recovered ranging code and the ideal ranging code of all signals.

Detection : The monitoring receiver acquire navigation signal, and then evaluate amplitude attenuation and curve distortion which is caused by wave distortion.

GNSS interoperable parameters

Correlation Characteristics

(Continued)

Calculation method:

Correlation function:

$$CCF(\varepsilon)=\frac{\int_0^{T_p} S_{BB-\mathrm{PreProc}}(t)\cdot S^*_{\mathrm{Ref}}(t-\varepsilon)dt}{\sqrt{(\int_0^{T_p}\left|S_{BB-\mathrm{PreProc}}(t)\right|^2 dt)\cdot(\int_0^{T_p}\left|S_{\mathrm{Ref}}(t)\right|^2 dt)}}$$

$S_{BB\text{-}PrePeoc}$ is the base-band signal been pretreated (down conversion, Doppler removal); reference signal S_{Ref} is ideal base-band signal generated by local receiver; integral time T_p is the main code period of reference signal.

Relative loss:

Power loss of available signal to all received signals：

$$P_{CCF}[dB]=\max_{\substack{over\\ all\varepsilon}}(20\cdot\log_{10}(\left|CCF(\varepsilon)\right|))$$

GNSS interoperable parameters

Phase Coherence

Definition: The relative change of signal elements in the timeline.

Code and carrier Coherence : Relative jitter value between ranging code and carrier wave in the same signal branch.

Codes Coherence: Relative jitter value of time delay between ranging code and carrier wave; relative jitter value of ranging codes in different signal branch.

Detection : Monitor the navigation signal.

Calculation: Coherence between code and carrier & Coherence in ranging codes

GNSS interoperable parameters

Phase Coherence

(Continued)

Calculate method:

Code and carrier Coherence:

In interval of $[t,t+T]$, use carrier wave limited in L_j and L_k as radiation of code carrier wave in L_i frequency:

$$CCD_{Lj,Lk}^{Li}(t,t+T) = PR_{Li}(t+T) - PR_{Li}(t) - [CR_{Li}(t+T) - CR_{Li}(t)]$$

$$-2\left(\frac{f_{L1}}{f_{Li}}\right)^2 \Delta I_{Lj,Lk}(t,t+T)$$

$\triangle I_{Lj,Lk}(t,t+T)$ denotes the ionospheric delay differences in L_1 frequency on interval $[t,t+T]$, these differences calculated from D-value of L_j and L_k frequency amplitude.

If $CCD^{Li}{}_{Lj,Lk}(t,t+T)$ neets:

$$\mathbf{100 \leqslant T \leqslant 7200,\ t_1 \leqslant t \leqslant t_2 - T,\ CCD^{Li}{}_{Lj,Lk}(t,t+T) > 6.1\ m}$$

Thus, code and carrier wave are consistence at $t+T$.

GNSS interoperable parameters

Phase Coherence

(Continued)

Calculate method:

Coherence in ranging codes:

$$\rho_i' = \rho_i + \lambda_i^2 \frac{\Phi_j - \Phi_i}{\lambda_j^2 - \lambda_i^2}, \ \rho_j' = \rho_j + \lambda_j^2 \frac{\Phi_i - \Phi_j}{\lambda_i^2 - \lambda_j^2}, \ \Delta\rho = \rho_i - \rho_j - \Delta\rho_{i,j}$$

ρ_i', ρ_j', ρ_i, ρ_j represent pseudo-range when exist ionospheric error and no ionospheric error respectively, j represent frequency which is different from i. Φ_i and Φ_j are observation value of carrier phase(the unit is distance), wavelength are λ_i and λ_j respectively; $\lambda^2_i(\Phi_j - \Phi_i)/(\lambda^2_j - \lambda^2_i)$ is amended value of dual-frequency ionosphere; $\Delta\rho$ represent time delay between receiver channels.

GNSS interoperable parameters

Orbit

Definition: GNSS precise orbit calculated based on same monitor station, same orbit determination algorithm, same space-time reference.

Detection : Utilize observation value of multi-mode receiver and precise orbit algorithm to calculate GNSS precise orbit.

Calculation:

a) Detect the coarse error of observation value and cycle slip;

b) Using the processed data to the precision of satellite orbit, station location and ERP parameter estimation;

c) Obtained by compare to the correction information of broadcast ephemeris orbit .

GNSS interoperable parameters

Clock offset

Definition: Calculate GNSS precise clock error based on same monitor station, same orbit determination algorithm, same space-time reference.

Detection : Utilize Observation data of Laser, radio, dual-frequency carrier wave and precise clock error algorithm to get precise clock error of GNSS.

GNSS interoperable parameters

Clock offset

(Continued)

Calculation:

a) Detect the coarse difference and cycle slip of the observation data;

b) Take real-time precise satellite orbit, the position of observation station, and EPR parameters as known parameters to real-time precise satellite clock error processor;

c) Use preprocessed real-time observation data by means of Square Root Filter to evaluate clock error;

d) Compare the evaluated clock error with the broadcasted clock error, and then get amended clock error information.

GNSS interoperable parameters

Ionosphere

Definition: Total electron content of global ionospheric grid based on the calculation of dual-frequency observations.

Detection : By monitoring of ionospheric grid model.

Calculation: a) Total electron content (TEC) in the path from monitoring station to satellite:

$$\tilde{P}_{1,i}^{k} - \tilde{P}_{2,i}^{k} = (1-\xi)\frac{40.28 \cdot TEC}{f_1^2} + \Delta b^k + \Delta b_i$$

b) Work out total electron content of global ionospheric grid by geomagnetic model:

$$TEC(\phi,\lambda) = \sum_{n=0}^{n_{d\max}} \sum_{m=0}^{n} \tilde{P}_{nm}(\sin\varphi) \cdot \left(\tilde{A}_{nm}\cos(m\lambda) + \tilde{B}_{nm}\sin(m\lambda)\right)$$

GNSS interoperable parameters

GNSS time bias

Definition: The time differences between each satellite navigation system and UTC.

Detection : Monitor each system time and compare with UTC.

Calculation: 1）Calculate the differences Δ_{sys} between each system time and UTC(K),

$$\Delta_{sys}=T_{sys}-UTC(K);$$

2）Worked out the difference Δk between UTC(K) and UTC,

$$\Delta k=UTC(K)-UTC;$$

3）Normalized each system time to UTC,

$$\Delta=\Delta_{sys}+\Delta k.$$

GNSS interoperable parameters

GNSS coordinate bias

Definition : Differences between coordinate reference frame and ITRF.

Detection : Measure the coordinate of given points in different coordinate reference frame, then calculate their difference

Calculation : $(X_n, Y_n, Z_n)^T_i$: the coordinate of P_n in frame i, $(X_n, Y_n, Z_n)^T_{\mathrm{ITRF}}$: the coordinate of P_n in ITRF; then (using Bursa model):

$$\Delta P_{n,(\mathrm{ITRF},i)} = \begin{bmatrix} X_n \\ Y_n \\ Z_n \end{bmatrix}_{\mathrm{ITRF}} - \begin{bmatrix} X_n \\ Y_n \\ Z_n \end{bmatrix}_i = \begin{bmatrix} dX_n \\ dY_n \\ dZ_n \end{bmatrix} + \begin{bmatrix} dm & \varepsilon_3 & -\varepsilon_2 \\ -\varepsilon_3 & dm & \varepsilon_1 \\ \varepsilon_2 & -\varepsilon_3 & dm \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_i$$

$$\Delta_{\mathrm{ITRF},i} = E\left(\Delta P_{(\mathrm{ITRF},i)}\right) \pm k \times \sqrt{D\left(P_{(\mathrm{ITRF},i)}\right)^2}, \quad k = 1, 2, 3$$

GNSS interoperable parameters

TGD

Definition: GNSS signal group time delay

Detection : Monitor and compare the signal time delay

Calculation:

$$TGD(f_i, f_j) = \frac{PR(f_i) - PR(f_j)}{1 - (f_i / f_j)^2}$$

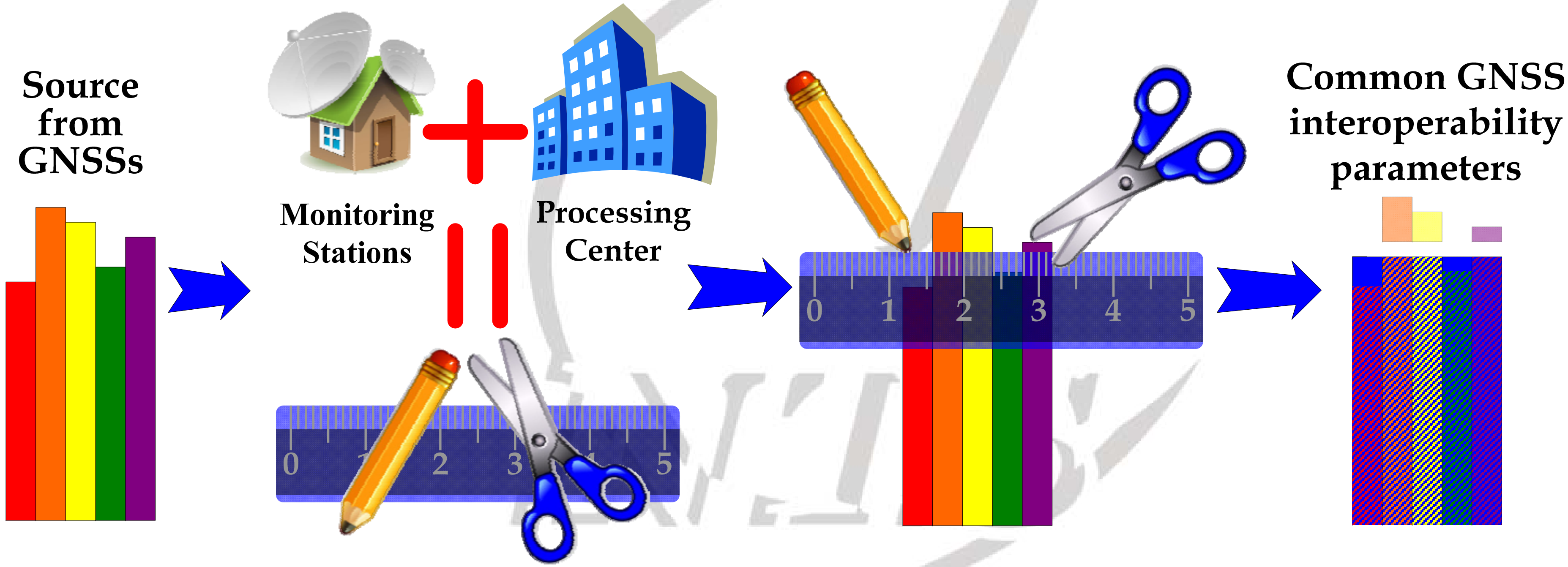
Where, f_i and f_j are carrier wave frequency of two GNSS signals, PR(f_i) and PR(f_j) are the corresponded signal group time delay.

GNSS Interoperability

Two forms can represent the parameters:

The precision data point the assessment result.

The tolerance data point the difference between the monitoring result and the assessment result.



Form of interoperable parameters

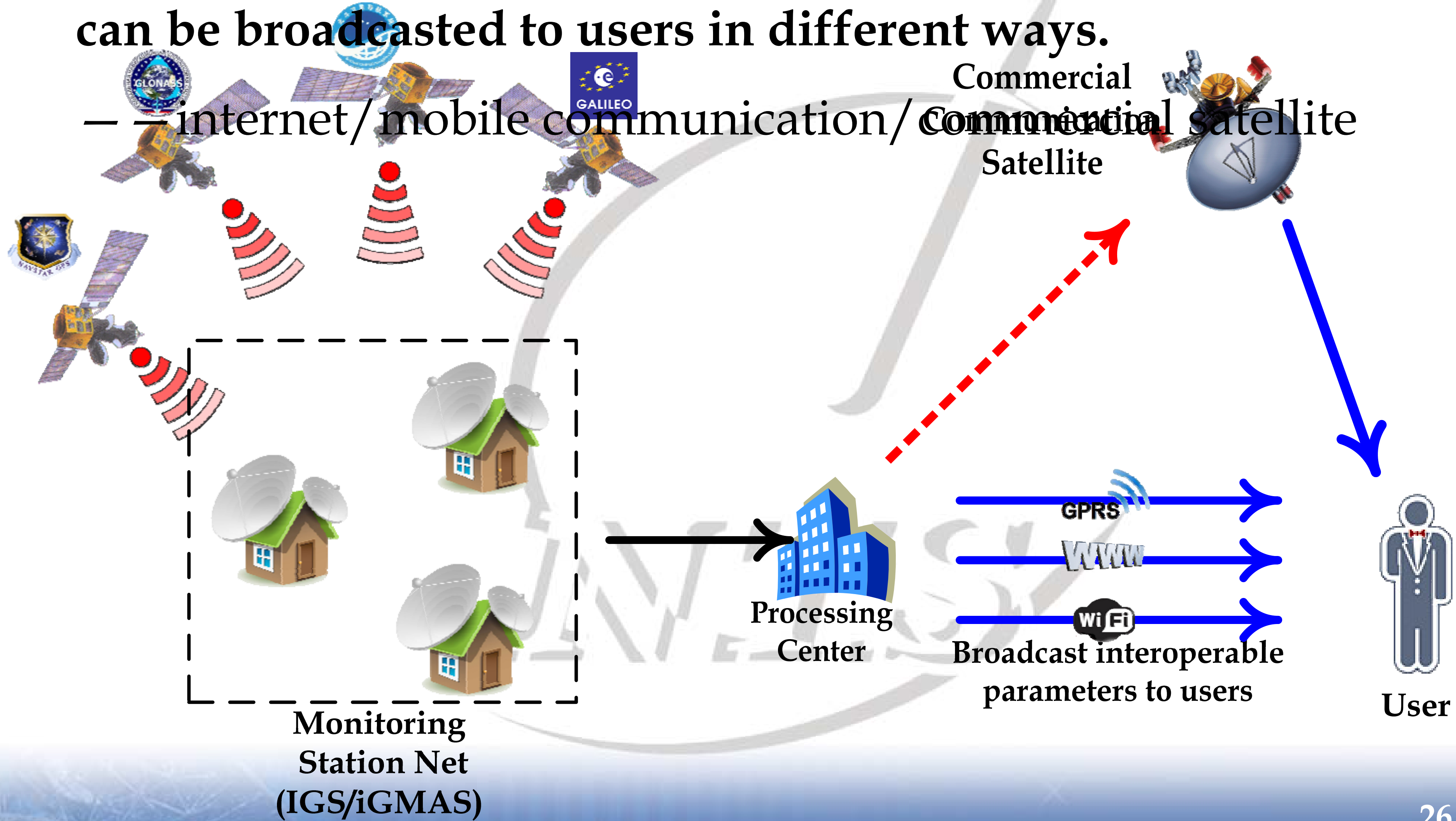
Comparison of the two forms:

	Advantages	Disadvantages
Precision data	Less computational complexity of user receiver Less computational complexity of the third monitoring station	Need high data rate Increased the time of receiving complete information The system will be useless when the parameters of the third party is unavailable
Tolerance data	Low requirements of data rate Receive complete information in short time Can still use original GNSS to realize PVT when the parameters of the third party are unavailable	Additional process at user receiver Increased the amount of computation in the third monitoring station

Broadcasting interoperable parameters

Except the providers own links, interoperable parameters can be broadcasted to users in different ways.

– internet/mobile communication/commercial satellite



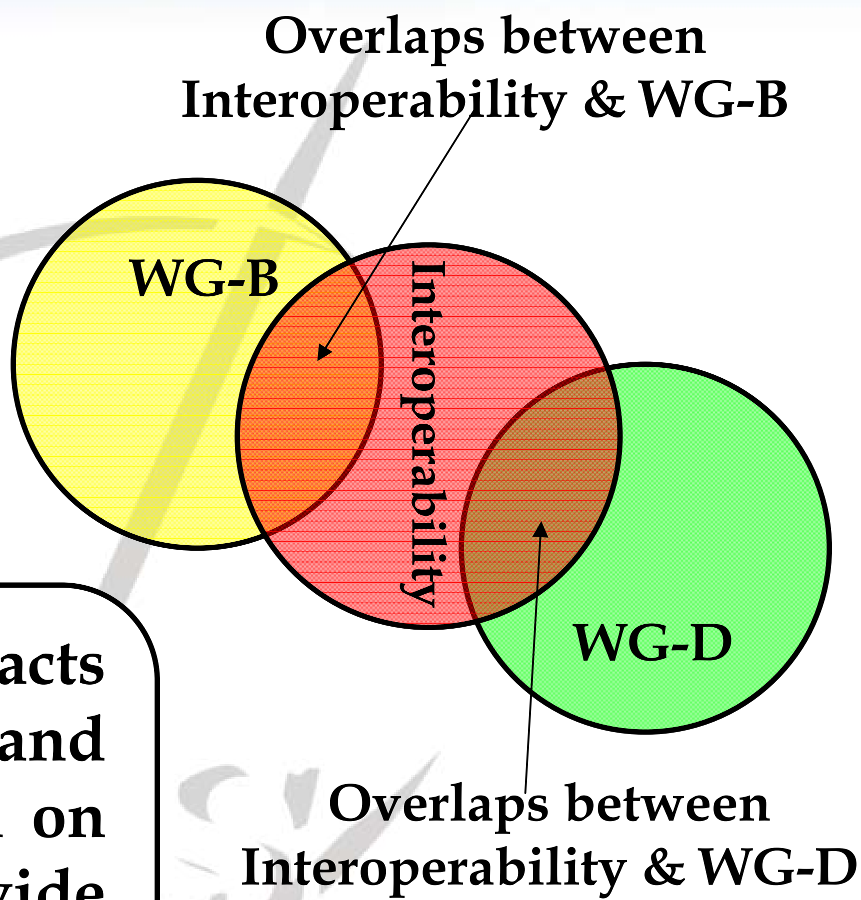
Conclusion

Other issues about GNSS interoperability:

DOP amelioration of multi-GNSS	The third frequency for interoperability
DOP saturation value	Frequency diversity
Utilize existing or planned spare capacity in civil/open service navigation messages to increase multi-GNSS interoperability	Definition, model and calculation of interoperable parameters
Utilize existing or planned spare capacity SBAS navigation messages in order to increase multi-GNSS interoperability	Monitoring method in interoperable parameters (include system time difference monitoring)
Patent of MBOC signal	System time difference monitoring
Receive multi-system observation data	interoperable parameters broadcasting
Technology on receiving interoperable signal and receiver	Correction model of ionosphere and atmospheric delay in multi-GNSS
interoperable parameter model and algorithm taken by users	Correction model of solar radiation pressure in multi-GNSS
Data type consistency and transferability	Other methods to enhance interoperability

Conclusion

WG-B and WG-D have paying more attention to overlaps between their work and in-depth interoperability research.



A platform is required to attracts more academic, experts and industry specialists to research on interoperability and to provide better services for users.

Conclusion

Under this platform, we can discuss the following topics :

- Interoperable signal
- interoperable parameter
- Interoperability in user level
- Methods to enhance interoperability
- Interoperable algorithm
- ……


Thank You for
Your Attention!
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