Improvement of GLONASS Time Generation and Its Synchronization to UTC(SU)

A.S. Bandura, P.P. Bogdanov, A.V. Druzhin, A.E. Tiuliakov, A.Y. Feoktistov

"Russian Institute of Radionavigation and Time" JSC, Saint-Petersburg, Russia

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Introduction

Global Navigation Satellite System GLONASS provides high-accuracy determination of position, velocity and time for land, marine, air and other kinds of users.

To achieve this the time scales of all space vehicles are synchronized to GLONASS Time and GLONASS Time is synchronized to time scale used as a reference.

GLONASS Reference Time scale is Russian national time scale UTC(SU) generated by State Time/Frequency Reference.

Now GLONASS characteristics in terms of the accuracy of GLONASS Time and UTC(SU) broadcast to users meet specified requirements. However, for time users they are not high enough as compared with GPS.

The paper presents the main principles of GLONASS Time generation and its synchronization to UTC(SU) as well as the main approaches that can increase their accuracy.

GLONASS Time Generation

GLONASS Time is generated as a continuous "paper" time scale on the base of the Main and/or Reserved Central Synchronizer (CS) using the following formula:

$$\Delta T_{GL}(t) = \Delta T_M(t) + \Delta T_M^{ph}(t_i) + \Delta T_M^{fr}(t_j) - \Delta T^c(t) =$$

$$= \Delta T_R(t) + \Delta T_R^{ph}(t_k) + \Delta T_R^{fr}(t_l) - \Delta T^c(t) - \Delta T_{M-R}(t)$$

where $\Delta T_{GL}(t)$ - GLONASS Time offset relative to Reference Time;

$\Delta T_M(t), \Delta T_R(t)$ - Main/Reserved CS time offset relative to Reference Time;

$\Delta T_M^{ph}(t_i), \Delta T_R^{ph}(t_i)$ - corrections for Main/Reserved CS phase steering;

$\Delta T_M^{fr}(t_j), \Delta T_R^{fr}(t_j)$ - corrections for Main/Reserved CS frequency steering;

$\Delta T^c(t)$ - correction for controlling GLONASS Time - Reference Time offset;

$\Delta T_{M-R}(t)$ - the offset between Main and Reserved CS Time.

GLONASS Time Generation

CS accuracy parameters:

– relative frequency error – within $\pm 3 \cdot 10^{-14}$;

– daily frequency instability – below $2 \cdot 10^{-15}$.

The backbone of CS is Frequency/Time Keeping Facility (FTKF) including four active Hydrogen Frequency Standards (HFS), a system for internal comparisons and a system for steering frequencies and phases of signals from HFS.

HFS which provides the best accuracy characteristics on the results of internal comparisons becomes master standard, the others operate as secondary.

GLONASS Time Generation

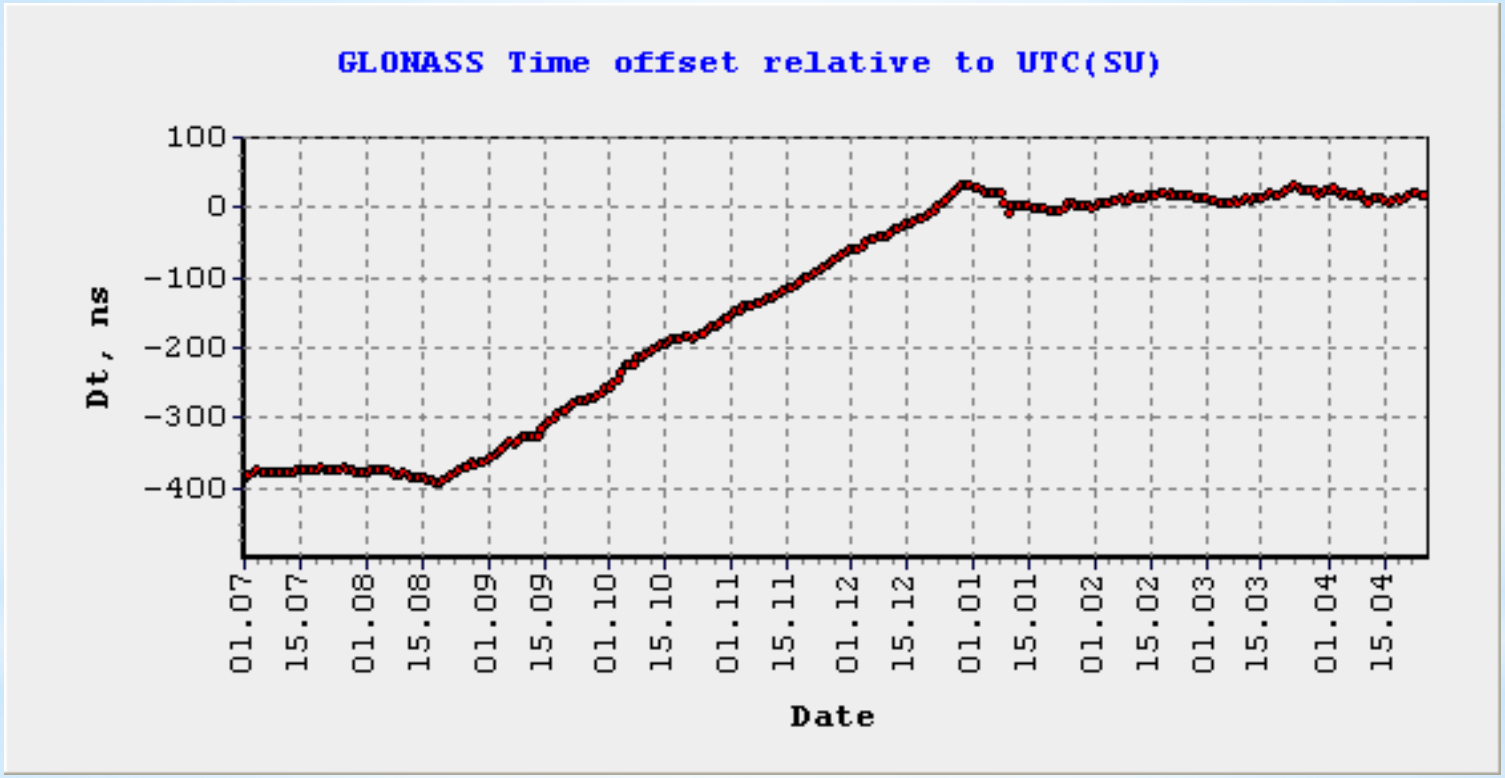
CS time scale is corrected by ± 1 s simultaneously with the correction of coordinated time scale UTC and, as a result, there is no whole second time offset between GLONASS Time and UTC(SU).

However, there is a three-hour constant offset between GLONASS Time and UTC(SU) due to GLONASS Monitoring and Control Segment operational principles.

Till August 2014 the offset of GLONASS Time relative to UTC(SU) was about 400 ns. It met specified requirements but was not satisfactory for time users.

Therefore, to increase the accuracy of GLONASS Time synchronization to UTC(SU) on 18th August, 2014 the procedure for GLONASS Time correction by changing the value of controlling correction was started. To keep the specified accuracy of SV time scales synchronization to GLONASS Time the value of daily correction change was 3 ns.

GLONASS Time Generation



GLONASS Time Synchronization to UTC(SU)

The offset of CS time scale relative to STFR time scale is calculated on the base of their mutual comparisons by the signals from SVs of GLONASS and GPS in differential mode with using "all-in-view" method according to the following formula:

$$\Delta T_{STFR-CS} = \Delta T_{GL(GPS)-CS} - \Delta T_{GL(GPS)-STFR}$$

where $\Delta T_{STFR-CS}$ - CS time scale offset relative to STFR time scale;

$\Delta T_{GL(GPS)-CS}$ - CS time scale offset relative to GLONASS/GPS Time;

$\Delta T_{GL(GPS)-STFR}$ - STFR time scale offset relative to GLONASS/GPS Time.

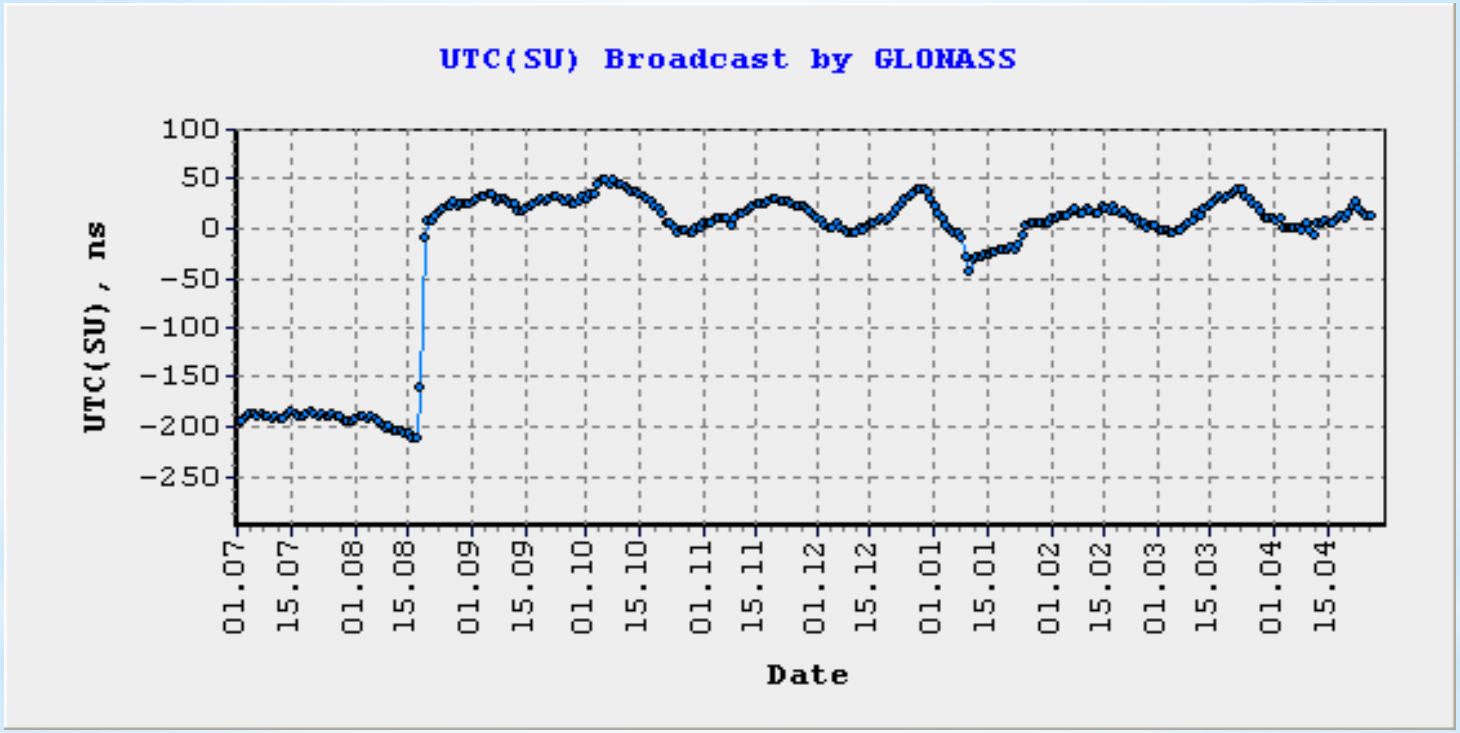
Now the error of calculating Main CS - STFR time scale offset is about 8 ns (rms), Reserve CS - STFR time offset is 13 ns (rms).

GLONASS Time Synchronization to UTC(SU)

Till 18th August, 2014 the error of broadcast corrections for GLONASS Time – UTC(SU) offset contained a systematic component of approximately 200 ns. Therefore, on 18th August, 2014 the generated corrections to GLONASS Time were also changed.

Now the error of broadcast corrections for GLONASS Time – UTC(SU) offset does not exceed 10 ns (rms).

UTC(SU) Broadcast to Users



Increasing the Accuracy of GLONASS Time Generation and Its Synchronization to UTC(SU)

The main approaches used to increase the accuracy of GLONASS Time generation and its synchronization to UTC(SU) are:

- to increase CS accuracy characteristics;

- to increase the accuracy of GLONASS Time synchronization relative to UTC(SU);

- to increase the accuracy of broadcast to users corrections to GLONASS Time relative to UTC(SU).

Increasing the Accuracy of GLONASS Time Generation and Its Synchronization to UTC(SU)

The second and third approaches are going to be realized, first of all, by increasing the accuracy of time scale comparisons between CS time scale and STFR, so it is planned:

- at the 1st stage to install similar calibrated GLONASS/GPS time receivers at STFR and CS. It can provide to determine time scales offset with the error of about 3 ns;

- at the 2nd stage to use time transfer facilities using duplex communication links through satellites in geosynchronous orbit (GEO). It can provide the accuracy of about 1 ns.

To achieve it a new Time Transfer Unit (TTU-1) based on 36-channel dual-frequency GLONASS/GPS receiver by Standard Precision (SP) signals in L1 and L2 frequency bands was additionally installed at CS and STFR and new GTR-51 time receiver by ST and precise (P) signals in L1 and L2 frequency bands was additionally installed at STFR.

Improvement of GLONASS Time Generation and Its Synchronization to UTC(SU)

Results of accuracy estimates for mutual time scales comparisons with using TTU-1

Sites	Comparisons error (rms), ns					
	GLONASS		GPS		GLONASS+GPS	
	L1C	L3C	L1C	L3C	L1C	L3C
STFR2 – CS_M	0.6-1.6	2.4-2.7	0.3-1.6	1.7-2.2	2.2-3.5	7.1-7.5
STFR2 – CS_R	4.1-7.3	4.0-4.7	3.2-6.1	2.6-3.1	5.0-9.3	7.0-7.6
CS_M – CS_R	4.0-7.1	1.7-2.4	4.7-8.2	3.7-4.6	5.5-9.7	3.9-4.6

Improvement of GLONASS Time Generation and Its Synchronization to UTC(SU)

Results of accuracy estimates for mutual time scales comparisons with using TTU-1 and GTR-51

Sites	Comparisons error (rms), ns					
	GLONASS		GPS		GLONASS+GPS	
	L1C	L3P-L3C	L1C	L3P-L3C	L1C	L3P-L3C
STFR1–STFR2	1.2-2.4	2.4-2.9	0.2-1.7	1.3-1.6	3.1-6.6	7.4-11.5
STFR1 – CS_M	0.8-1.6	1.4-1.8	0.3-1.6	2.1-2.5	3.4-3.9	4.8-10.4
STFR1 – CS_R	3.8-6.7	2.2-3.2	4.2-8.1	2.4-3.3	5.3-9.2	5.0-11.7

Increasing the Accuracy of GLONASS Time Generation and Its Synchronization to UTC(SU)

The results presented in Tables 1, 2 show that using new equipment for time scales comparisons at CS and STFR provides noticeable increase of remote clock comparisons accuracy by GLONASS signals:

- the error of time scales comparisons between Main CS and STFR with using single-frequency measurements in L1 band – about 1.2 ns (rms) by GLONASS signals and 1.0 ns (rms) by GPS signals;

- the error of time scales comparisons between Reserve CS and STFR with using dual-frequency measurements – about 4,3 ns (rms) by GLONASS signals and 2.8 ns (rms) by GPS signals.

Conclusions

Now GLONASS accuracy characteristics meet specified requirements.

As a result of further GLONASS development the following accuracy characteristics are planned to be achieved:

- GLONASS Time - UTC(SU) offset below 20 ns at the 1st stage and 4 ns at the 2nd stage;

- the error of broadcast corrections to GLONASS Time relative to UTC(SU) below 5 ns at the 1st stage and 2 ns at the 2nd stage.

Thank you for your attention!