FIRST RESULTS FROM GLONASS COMMON-VIEW TIME COMPARISONS REALIZED ACCORDING TO THE BIPM INTERNATIONAL SCHEDULE

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Abstract

Currently the most popular method of comparing remote clocks is to use the GPS and GLONASS satellite navigation systems. The comparisons via GLONASS signals were suspended for many years because full deployment of the system was delayed and there were no commercial time receivers. This paper presents the first results from GLONASS common-view time comparisons, obtained using a GLONASS receiver of type ASN-16 from Russian Institute of Radionavigation and Time (RIRT) and an R-100 type of 3S Navigation while following a BIPM tracking schedule.

INTRODUCTION

The use of GLONASS signals which, for time synchronization, have characteristics similar to those of GPS was restricted for a long time because there were no commercial time receivers. In late 1993, the Russian Institute of Radionavigation and Time (RIRT) completed the development of a GLONASS time receiver, satisfying BIPM requirements and based on its own airborne ASN-16 receiver. To obtain and process GLONASS time measurements automatically, an interface between the ASN-16 and a personal computer was built. In the near future these receivers will be put into operation at the Russian State Time/Frequency

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Reference in VNIIFTRI, Mendeleevo, and in other Russian Time Service laboratories. In mid-1995, 3S Navigation commercialized the GLONASS R-100 receiver in accordance with BIPM requirements. These receivers were installed at the BIPM, USNO, VSL, NIST, DLR, and other laboratories. After the appearance of these special timing receivers, the BIPM published the first tracking schedule for international time and frequency comparisons by GLONASS common views. Regular measurements and data exchange between laboratories began 4 January 1996.

This paper provides a tentative estimation of the uncertainty of time comparisons by GLONASS common views, describes the main characteristics of the ASN-16 and R-100 receivers, and gives the first results of time comparisons between several laboratories in Europe and North America according to the BIPM international GLONASS schedule.

METHODS OF CLOCK SYNCHRONIZATION VIA GLONASS SIGNALS

The common-view method presupposes that multiple clock sites simultaneously measure a satellite's signals and exchange their results.[1] The mutual difference of clock times ΔT_{A-B} between two locations A and B is determined from the relationship:

$$\Delta T_{A-B} = \Delta T_A - \Delta T_B, \tag{1}$$

where ΔT_A and ΔT_B represent the offsets of the clocks from GLONASS time. The time difference between the user clock and the GLONASS time is given by the relationship:

$$\Delta T = S - \tau_{rel} - \tau_{ion} - \tau_{trop} - \tau_{rec} - D/c + \Delta T_{sat}, \tag{2}$$

where S is the measured pseudorange between the satellite and the user (that is, the difference in two identical codes: one received by the receiver, the other generated by the receiver; each synchronized by its own clock); τ_{rel} is a relativistic term; τ_{ion} is the propagation delay due to the ionosphere; τ_{trop} is the propagation delay due to the troposphere; τ_{rec} is the receiver delay; D is the distance from the satellite to the user; c is the speed of light; and ΔT_{sat} is the difference between satellite clock and GLONASS time.

The distance from the satellite to the user is computed on the basis of broadcast ephemerides x_i, y_i, z_i and the known coordinates of the receiver antenna x_A, y_A, z_A. The difference between the satellite clock and GLONASS time is determined on the basis of time and frequency corrections τ_i and γ_i, where τ_i is the time scale shift t_i of the ith satellite relative to the GLONASS time, and γ_i is the relative difference between the calculated carrier-frequency value of the radiated navigation radio-frequency signal of the ith satellite and its nominal value.

Because the GLONASS navigation message does not include model parameters, the user computes the ionospheric delays either using models based on fixed parameters stored autonomously in the single frequency receiver or using a two-frequency technique. In both cases a model is used to compute the tropospheric delays. The receiver delay is determined by calibration.

From Eq. (2), it follows that accuracy of measurements is defined by: the uncertainty in measurements of the pseudorange; the instability of the receiver delay; inaccuracy in accounting for the relativistic term; inaccuracy in modelling the ionospheric and tropospheric delays; the uncertainty in the antenna coordinates; the uncertainty of the satellite ephemerides; and the error of the satellite clock. As several components are common to A and B, the accuracy of the difference is significantly better than that of the individual values.

Table 1 gives tentative uncertainty budgets for GLONASS time comparisons in common-view mode, at distance d, for C/A-code receivers, for one 13-minute track and for the average of 30 tracks over one day. In making these calculations it is assumed that: the noise of the laboratory clocks and the rise time of the reference pulses are negligible; ground antenna coordinate uncertainties are of the order of 10 m; ephemerides uncertainties are of the order of 25 m; and a model with fixed parameters is used to determine the ionospheric delay.

BRIEF DESCRIPTION OF GLONASS TIME RECEIVERS

Table 2 lists laboratories which observe GLONASS according to the tracking schedule for international time and frequency comparisons by GLONASS common views and laboratories which have expressed interest in using GLONASS common views. The ASN-16, designed by RIRT, is a one-channel, one-frequency unit designed for airborne navigation.[2] When used for time determination, it provides, via one chosen satellite, an output of 1 Hz synchronized to GLONASS time. That is why, for time comparisons via GLONASS signals using the ASN-16 receiver, an additional time intervallometer is necessary. To eliminate the need for this instrument the ASN-16 receiver was redesigned to provide a time difference with an external signal of 1 Hz. In this form, the ASN-16 receiver is designated ASN-16-02 and it provides fully automated measurements through an interfacing to a PC. The uncertainty of time determination between the user clock and satellite clock by this receiver is not worse than 60 ns (rms). Tests of two ASN-16-02 receivers at the RIRT show, that uncertainty of GLONASS common-view time comparisons is not worse than 10 ns (rms) for averages including not less than 15 tracks per day.

Receivers of the type R-100 are manufactured by 3S Navigation. The R-100/10 receiver is also one-channel, one-frequency, C/A-code unit. It provides time differences between the user clock and the satellite clock with an uncertainty not worse than 60 ns (rms) and common-view time comparisons with an accuracy of a few nanoseconds (rms) when calibrated relatively. The R-100/30 receiver is a two-channel, two-frequency, two-system GPS/GLONASS, instrument which uses P-code for GLONASS and C/A-code for GPS. It provides independent measurements for each channel and for GLONASS accounts for ionospheric delays by the two-frequency technique. The uncertainty of time determination between the user clock and satellite clock is not worse than 60 ns (rms) and the accuracy of common-view time comparisons is a few nanoseconds (rms) for differentially calibrated receivers.

Both receivers are controlled by a PC and use a standard format developed for GPS common-view technique by the CCDS Group on GPS Time Transfer standards.[3] The R-100 receivers use also the standard formulae and parameters adopted for GPS. The ASN-16-02 receiver does not follow these standards.

ESTIMATION OF GLONASS COMMON-VIEW TIME TRANSFER UNCERTAINTY

In this paper we consider ten time links on baselines ranging from zero to 9,000 km. We show that the baseline length affects the precision and accuracy of satellite common-view time transfer. The greater the distance, the larger the effect of uncertainties in the satellite ephemerides and ionospheric delay on time transfer. However, uncertainties of the antenna coordinates (see Table 1) may add a major contribution to the uncertainty of the common-view link even over a short baseline.

Table 3 shows the results of uncertainty estimations of GLONASS common-view time comparisons between clocks in some laboratories noted above, for intervals of one month. We have chosen to express the uncertainties of GLONASS time links in terms of the root-mean-square (rms) of the differences between raw and smoothed values. The data analysis covers the nine-month period in which the first and second international GLONASS schedules were implemented. From 7 to 62 GLONASS common views were available daily. Vondrak smoothing[4], which acts as a low-pass filter with cutoff periods ranging from about 1 day for a 0-km baseline to about 10 days for a 9,000-km baseline, was performed on the raw GLONASS common-view values. This cutoff period was chosen as representing, approximately, the limit between short time intervals, for which measurement noise is dominant, and longer intervals, for which clock noise prevails. The number of common views per link and cutoff periods are given in Table 4. The results are illustrated by Figure 1. At the RIRT the method of least-squares interpolation was employed, together with a linear model for time differences with one-day averaging. The link RIRT - VSL is also reported with the RIRT approach (marked • in Table 3). The uncertainties derived from two methods are similar.

At the BIPM a procedure to remove constant biases between observations in different directions of the sky is used operationally for the treatment of GPS data. It has been shown for GPS common views that for the short baselines, up to 1,000 km, these constant biases are mostly due to errors in the differential coordinates of the laboratories involved.[5] We have chosen the link DLR - VSL to illustrate the use of this procedure for GLONASS common views. Figure 1 shows the common views before removal of biases, and Figure 2 shows the same views after removal of biases. The rms is reduced from 7.9 ns to 2.4 ns. This is a strong indication that differential coordinates between these two laboratories have an error of several meters. In fact we already know (see Table 1) that the GLONASS antenna coordinates at the DLR and VSL have errors of several meters in the ITRF. The reasons of expressing GLONASS antenna coordinates in the ITRF reference frame are explained in detail in [6] elsewhere in these Proceedings.

To evaluate the performance of the GLONASS common-view method, we also computed the [UTC(DLR) - UTC(VSL)] by the GPS common-view method. The results are given in Table 5 and in Figures 3 and 4. There is a constant shift of 324 ns between the two methods, partly due to the use of uncalibrated GLONASS and GPS receivers and partly to the less accurate geodetic coordinates available for GLONASS. When a constant shift is removed from the difference between GPS and GLONASS results, values obtained are strikingly low, generally 1 ns. Figures 3 and 4 illustrate the removal of biases from GPS observations. The slight improvement, from 2.5 ns to 1.7 ns rms, is due to an error of about 0.5 m in differential coordinates between these two laboratories.

CONCLUSION

1) The appearance of special timing receivers of types ASN-16-02 from the RIRT (Russia) and R-100 from 3S Navigation (USA) has made it possible to begin regular international time comparisons of clocks using GLONASS common views according to the BIPM tracking schedule.

2) The first results show that the uncertainty of GLONASS common-view time comparisons is

of the order of a few nanoseconds (rms) for distances of up to 1,000 km, and of the order of 10 nanoseconds for intercontinental distances. This is comparable with the performance of GPS measurements.

3) The overall accuracy of GLONASS time links is inferior to that of GPS. Improvements will be made possible by: determination of accurate ground-antenna coordinates in the ITRF,

- differential calibration of GLONASS receivers,
- adoption of standardized software,
- double-frequency measurement of ionospheric delay,
- use of postprocessed precise ephemerides,
- keeping the antennas in constant temperature.[7]

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Table 1. Tentative uncertainty budgets for GLONASS common-view time comparisons.

Component	For a single track, /ns		For 30 tracks, /ns	
	d=1000 km	d=9000 km	d=1000 km	d=9000 km
Satellite clock error (cancel in CV mode)	0	0	0	0
antenna coordinates	60	60	11	11
Satellite ephemerides	4	40	1	7
Ionosphere (day time, normal solar activity, elevation > 20 deg.)	2	30	1	5
Troposphere (elevation > 20 deg.)	2	2	2	2
Instrumental delay (relative)	2	2	2	2
Receiver software	2	2	2	2
Multipath propagation	5	5	1	1
Receiver noise (13-min average)	3	3	1	1
Total	61	78	12	14

Table 2. Laboratories observing GLONASS and showing interest.

Laboratory	Equipment	Estimated uncertainty of GLONASS antenna coordinates in the ITRF /m
1. Laboratories observing GLONASS:		
BIPM (Sevres, France)	R-100/10 R-100/30 with GPS option	0,3
USNO (Washington D.C., USA)	R-100/10	0,1
NIST (Boulder, Colorado, USA)	R-100/30 with GPS option	
3S (California, USA)	R-100/10 R-100/30 with GPS option	10,0
RIRT (St.Petersburg, Russia)	ASN-16-01	10,0
VSL (Delft, Netherlands)	R-100/30 with GPS option	4,0
DLR (Oberpfaffenhofen, Germany)	R-100/30 with GPS option	3,0
BIRM (Beijing, China)	ASN-16-02	
2. Laboratories in preparation or showing interest:		
VNIIFTRI (Mendeleevo, Russia)	ASN-16-02	
TL (Chung-Li, Taiwan)	R-100/30	
NPLI (New Delhi, India)	R-100/10	
IFAG (Wettzell, Germany)	R-100	
CSIR (Pretoria, South Africa)	R-100/30	

Table 3. Estimated uncertainties of GLONASS common-view links.

Common-view links	Distance /km	Estimated uncertainty / ns								
		Date 1996								
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
BIPM(100/30)-BIPM(100/10)	0	4	4	4	4	4	4	4	4	4
BIPM(100/30) - VSL	400	-	-	-	-	10	10	10	10	10
VSL - DLR	400	-	-	-	-	8	7	9	8	8
BIPM(100/10) - DLR	500	-	-	-	-	9	9	8	9	8
BIPM(100/30) - DLR	500	-	-	-	-	9	9	7	8	8
RIRT - VSL	2100	-	-	-	14	13	13	16	15	15
RIRT-VSL*	2100	-	-	-	-	-	16	15	17	17
BIPM(100/30) - RIRT	2200	14	6	8	7	5	5	7	7	6
BIPM(100/30) - 3S	8400	16	18	13	11	-	-	-	-	-
RIRT - 3S	11000	23	17	15	-	-	11	-	18	16

* Computed by RIRT

Table 4. Number of common views per link and cut-off periods.

Common-view links	*Distance /km*	*Number of common views per day*	*Cut-off period /day*
BIPM(100/30)-BIPM(100/10)	0	41	1
BIPM(100/30) - VSL	400	27	1 to 2
VSL - DLR	400	41	1
BIPM(100/10) - DLR	500	38	1 to 2
BIPM(100/30) - DLR	500	62	1 to 2
RIRT - VSL	2100	16	5 to 6
RIRT-VSL*	2100	14	
BIPM(100/30) - RIRT	2200	18	1
BIPM(100/30) - 3S	8400	12	4 to 5
RIRT - 3S	11000	7	8 to 10

Table 5. Comparison of GPS and GLONASS common-view time transfer for August and September 1996 at five-day interval.

UTC(DLR)-UTC(VSL)				
MJD	by GPS /ns	by GLONASS /ns	GPS - GLONASS /ns	GPS - GLONASS - 324 /ns
50299.0	1862	1539	323	-1
50304.0	1860	1535	325	1
50309.0	1874	1549	325	1
50314.0	1887	1564	323	-1
50319.0	1892	1568	324	0
50324.0	1897	1572	325	1
50329.0	1905	1580	325	1
50334.0	1908	1581	327	2
50339.0	1912	1587	325	1
50344.0	1911	1587	324	-1
50349.0	1917	1591	326	1
50354.0	1906	1581	325	1

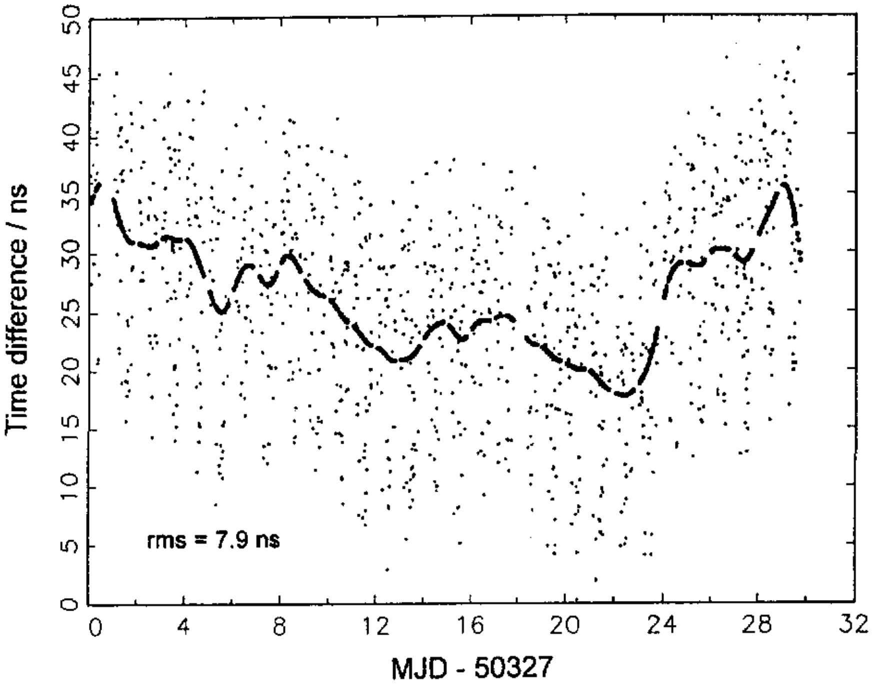

Figure 1. [*UTC(VSL) - UTC(DLR)*] plus a constant, by GLONASS common views.

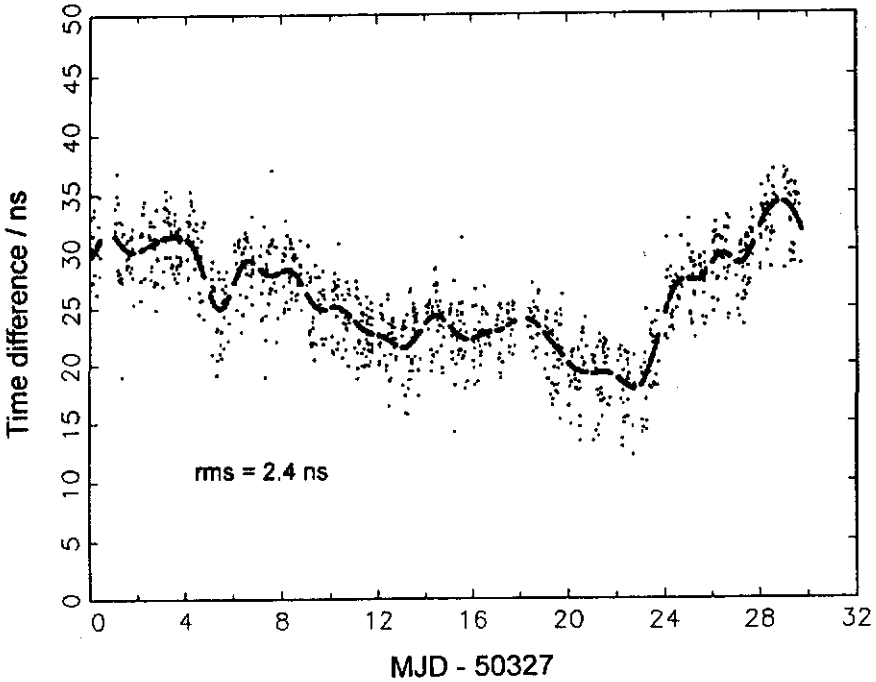

Figure 2. [*UTC(VSL) - UTC(DLR)*] plus a constant, by GLONASS common views after removal of the biases.

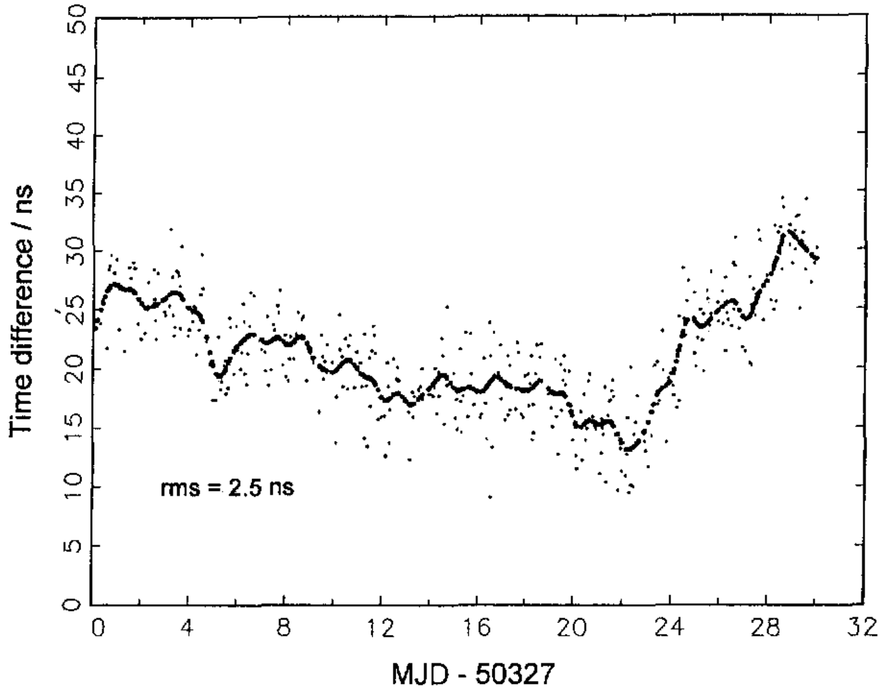

Figure 3. [*UTC(VSL) - UTC(DLR)*] plus a constant, by GPS common views.

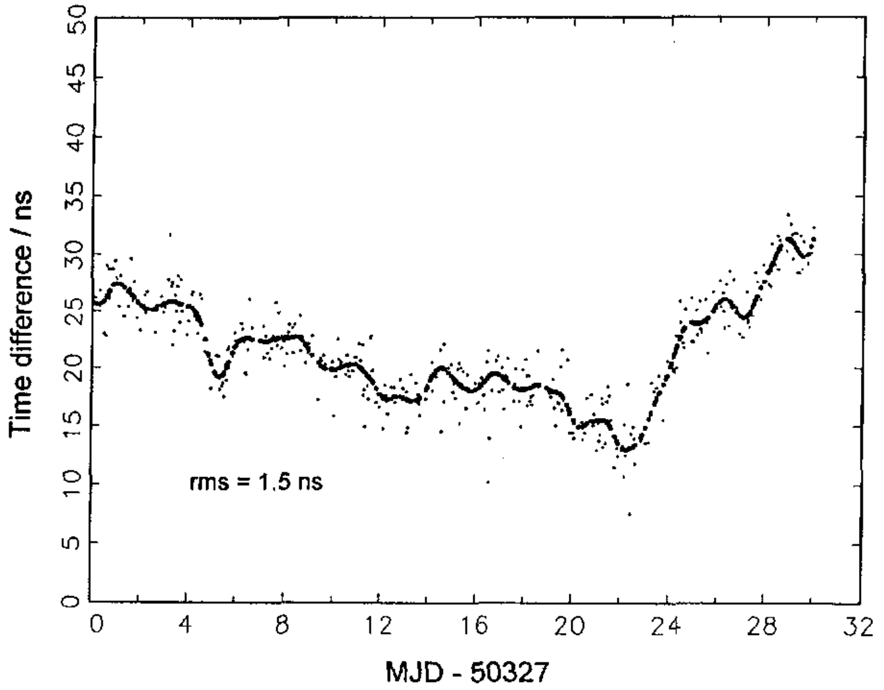

Figure 4. [*UTC(VSL) - UTC(DLR)*] plus a constant, by GPS common views after removal of the biases.