Real-Time Remote Calibration (RTRC) System for Time and Frequency

LIANG Kun, ZHANG Aimin
Division of Time and Frequency Metrology
National Institute of Metrology, NIM
Beijing, China
liangk@nim.ac.cn

ZUO Fei, PEI Chao
School of Electronics and Information Engineering
Beijing JiaoTong University
Beijing, China

ZHANG Side
Beijing Trust GPS Science&Technology Development Co., Ltd
Beijing, China

***Abstract*—Based on GNSS time and frequency transfer receiver of NIMTFGNSS-1 type, real-time remote calibration has been studied, and one new type of real-time remote calibration system named RTRC has been designed and implemented. The users who should be authorized can use RTRC(including one local NIMTFGNSS-1 receiver) to check and get real-time (16-minute latency) and historical data of remote calibration for their time scales and frequency standards on the web throughout the internet. Calibration uncertainties of the system for time and frequency have been evaluated as 6 ns and 2e-14 averaging one week respectively. For the user who has no time scale or frequency standard and needs either or both of them which time or frequency should be traced to UTC(NIM), National Time and Frequency Primary Standard of China, NIM can provide one low-cost rubidium clock as the accessory of NIMTFGNSS-1 receiver to make up one time scale disciplined by UTC(NIM) in real-time, its time and frequency stability averaging one day could be better than 5 ns and 3e-14 separately.**

Keywords-time and frequency; remote calibration; GNSS; atomic clock

I. INTRODUCTION

GNSS(Global Navigation Satellite System), especially GPS is one of the most useful tools for time and frequency transfer. With the quick development of GLONASS(GLObal Navigation System), BDS(Beidou Navigation Satellite System) and Galileo, GNSS time and frequency transfer becomes the more and more significant research direction. GNSS takes us the convenience of remote calibration for time and frequency. With the techniques of modern network communication, remote calibration base on GNSS time and frequency transfer in real-time is feasible.

At NIM (National Institute of Metrology, Beijing, China), real-time remote calibration(RTRC) system has been developed, and it is able to provide the timing users remote time and frequency measurement and calibration service in real-time for local time and frequency reference, and helps the metrology and timing laboratory to keep the local reference highly accurate and precise for the purposes of scientific research and metrology by remotely measuring the tiem difference between local reference and UTC(NIM)(at Changping campus) in real-time. It is easy for users to log on the website and check the real-time and historical time and frequency difference and some of their statistics.

II. DESIGN AND IMPLEMENTATION

The scheme of RTRC is illustrated as follows in Fig. 1. Each user who uses RTRC will receive one GNSS time and frequency transfer receiver of NIMTFGNSS-1[1] type(NIMGNSS-1 for short) and client software that performs the measurements and sends the instant results to RTRC central server for data storage and processing via internet. RTRC uses GNSS system as the common-view reference. NIMTFGNSS-1 and the central server are two main parts of RTRC. For user, the interface is shown in Fig. 2.

In processing, the system uses the data that are the same to CGGTTS REFSYS data of two stations every 16 min. Two stations may be the reference station NIM with UTC(NIM) and one user, or the two users. The time difference between two stations is calculated by processing of RTRC central server in real-time and the real-time or historical difference can be displayed on the webpage whenever the user logs on the RTRC web site.

If the user has no time and frequency standard, one UTC(NIM) disciplined rubidium clock with one NIMTFGNSS-1 by RTRC link can be combined as one UTC(NIM) disciplined oscillator, named NIMDO, which is provided to the user as his or her local time and frequency standard and has the advantage in the performance over GPSDO(GPS Disciplined Oscillator)[2,3]. The similar former research is NISTDO, and some detailed information can be found in [2] and [3]. NIMDO has the legal and direct traceability to UTC(NIM); its time and frequency accuracy and stability has been improved thanks to the high level reference time scale and time scale algorithm.

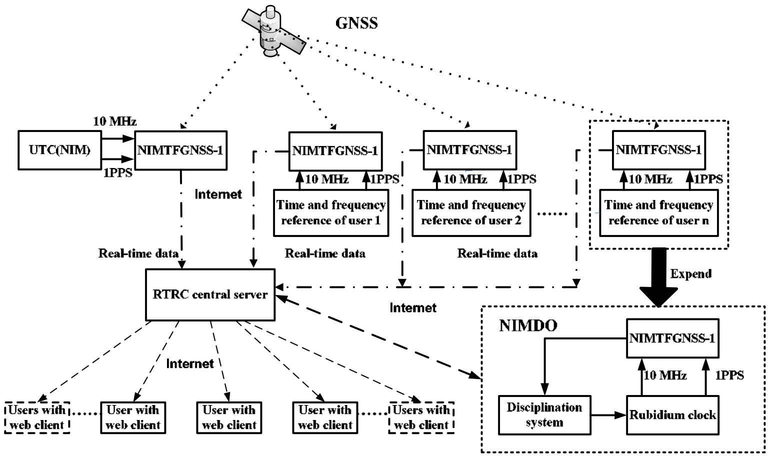

Figure 1. System scheme of RTRC

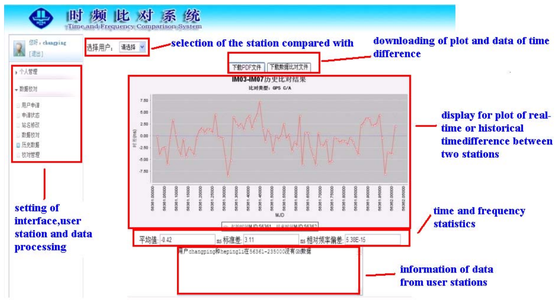

Figure 2. User interface of RTRC

III. Experiment Setup and Numric Results

Four kinds of experiments have been done for performance verification and evaluation of RTRC and NIMDO.

A. CCD(Common Clock Difference) Experiment

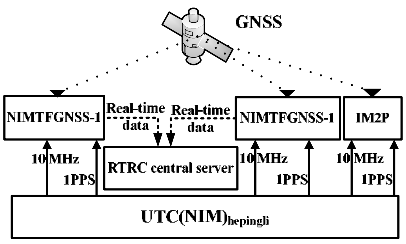

Figure 3. Schematic diagram 1

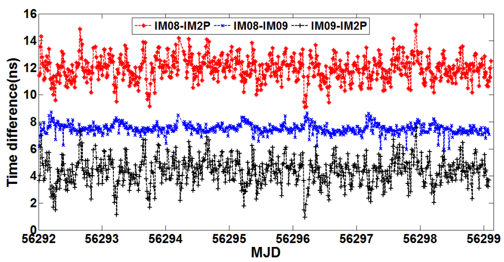

Figure 4. Results in the CCD experiment

To verify the noise level of RTRC system, the CCD experiment should be implemented. Three receivers IM08 and IM09(NIMTFGNSS-1), and IM2P(Septentrio PolaRx2eTR receiver) with the same time and frequency reference $UTC(NIM)_{hepingli}$(one cesium clock with one micro-stepper steered by UTC) at Hepingli campus of NIM, were involved in the experiment described in Fig. 3.

From Fig. 4, the standard deviations of CCD results for one week using the links of IM08-IM2P, IM08-IM09 and IM09-IM2P are 0.9 ns, 0.4 ns and 1.0 ns respectively. IM08 and IM09 have the excellent coherence with each other. Another reason for much smaller standard deviation for IM08-IM09 is that IM2P located very near to $UTC(NIM)_{hepingli}$ in the second floor is at least 20 meters far away from IM08 and IM09 located in the fourth floor, and we use more than 20 meters length radio cable for connection of two location. RTRC system uses the CGGTTS(CCTF Group on GNSS Time Transfer Standards) data indeed, so we use P3 code CGGTTS data of each link for demonstration of RTRC link noise level by post-processing.

B. Zero Baseline Experiment with the Different References

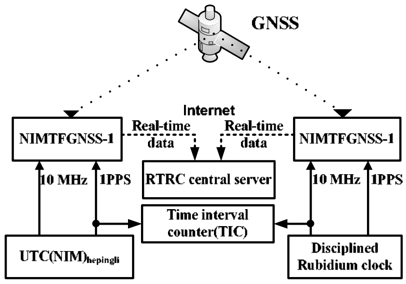

Figure 5. Schematic diagram 2

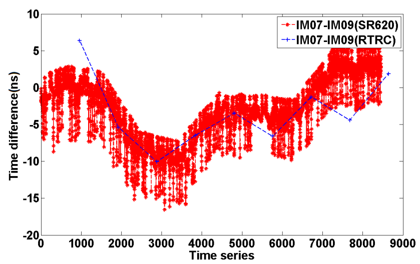

Figure 6. Comparison between RTRC and direct measurement

In Fig. 5, IM07(NIMTFGNSS-1) and IM08 at Hepingli campus with the reference to $UTC(NIM)_{hepingli}$ and the disciplined rubidium clock respectively were used to verify the calibration performance of RTRC, and in the meantime, for comparison, one local TIC(time interval counter, SRS SR620 type) was operated to measure the time difference between $UTC(NIM)_{hepingli}$ and NIMDO every second. The P3 code measurement every 16 min by RTRC is acquired from data downloading function of the system.

From Fig. 6, the trend of RTRC link agrees with that of direct measurement by TIC.

C. *Long Baseline Experiment*

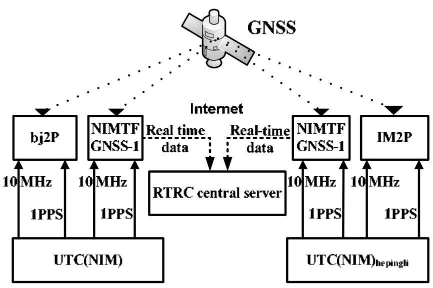

Figure 7. Schematic diagram 3

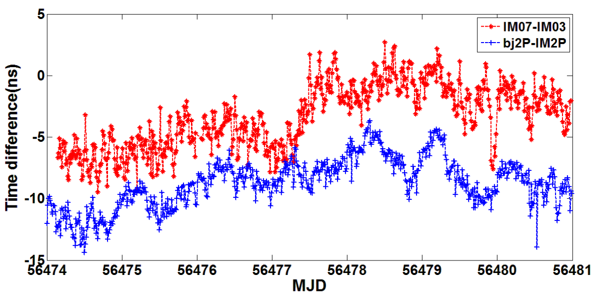

Figure 8. Comparison of two links in long baseline

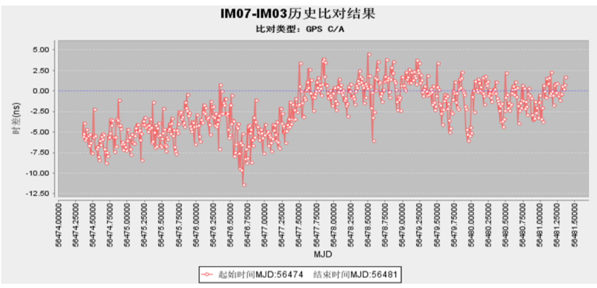

Figure 9. Real-time results by RTRC in long baseline

To show the calibration effect of RTRC directly, long baseline experiment has been implemented as shown in Fig. 6. The baseline between Hepingli campus and Changping campus is about 40 km. IM07 and IM2P referenced to $UTC(NIM)_{hepingli}$ are at Hepingli campus; IM03 and bj2P(Septentrio PolaRx3eTR receiver) referenced to UTC(NIM) are at Changping campus. The scheme of the experiment is described in Fig. 7.

Fig. 8 and 9 show the time difference between $UTC(NIM)_{hepingli}$ and UTC(NIM) with the links of IM07-IM03 by P3 code CGGTTS files, IM2P-bj2P by P3 code CGGTTS files and IM07-IM03 by C/A code measurements of RTRC in real-time from MJD 56474 to 56480. We see the quite similar results and correspondence with one another of three links. The standard deviations of time difference for three links are 1.5 ns, 1.0 ns and 1.4 ns separately. IM07 is located in the fourth floor that makes $UTC(NIM)_{hepingli}$ used for the reference of IM07 more noisy, and corresponds to the plots in Fig. 8 and 9.

D. *NIMDO Performance Verification*

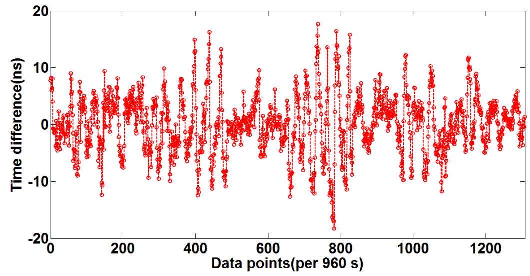

Figure 10. Time difference of NIMDO from UTC(NIM)

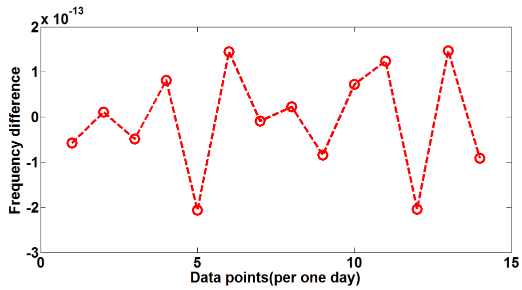

Figure 11. Frequency difference of NIMDO from UTC(NIM)

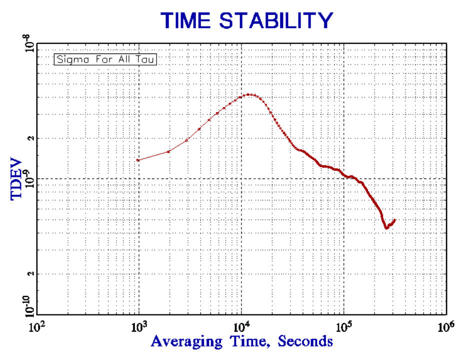

Figure 12. TDEV of NIMDO referenced to UTC(NIM)

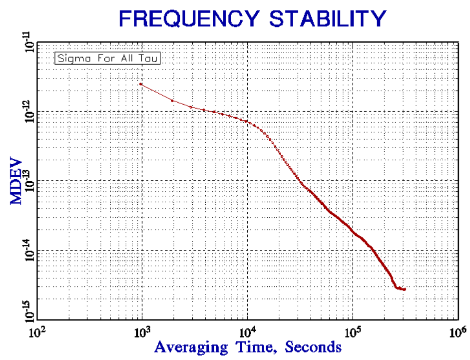

Figure 13. MDEV of NIMDO referenced to UTC(NIM)

The phase of the undisciplined rubidium clock is arbitrary and hasn't the good frequency stability because the big frequency drift. As well, the frequency accuracy would be worse and worse. For example, the direct measurement of one rubidium clock by one phase comparator for several days, its frequency stability (modified Allan deviation(MDEV)) for averaging time one hour and one day are 1.4×10^{-12} and 3.5×10^{-12} respectively, and the frequency accuracy is 1.1×10^{-10}.

Referenced to UTC(NIM), using the time difference data of about 15 days for the sampling interval 960 s by RTRC, frequency differences averaging one day were calculated, and we can reach preliminarily that in most situations the time and frequency accuracy of NIMDO could separately be within 10 ns and 1e-13 averaging one day as shown in Fig. 10 and 11; the time and frequency stability(time deviation(TDEV) and MDEV) averaging one day could be better than 5 ns and 3e-14 respectively illustrated in Fig. 12 and 13. The long frequency stability of the rubidium clock has been ameliorated due to the real-time and short latency steering to UTC(NIM).

IV. Uncertainty Analysis

Estimating the calibration uncertainty of RTRC involves evaluating the uncertainties using both Type A and Type B methods. In Type A method, we use statistical analysis by directly calculating the jitter (standard deviation) of measurement results for the link between two NIMTFGNSS-1 in the CCD experiment, and we can use the standard deviation of CCD results(0.4 ns for P3 code) shown in section 2, however, for GNSS C/A and P3 code measurements, 1.5 ns and 0.7 ns would be used usually by BIPM, and we choose the bigger one. Uncertainty evaluated by type B method, such as some theoretical analysis based on the experience, theory or authorized specification and manual, mainly includes several items as follows.

A. Calibration Uncertainty of GNSS Time and Frequency Transfer Receiver

Calibration uncertainty of GNSS time and frequency receiver using the differential method by BIPM is 5 ns, in generally. If two GNSS time and frequency transfer receivers have been calibrated, and the calibration uncertainty should be cancelled by most part of 5 ns, so the compound standard uncertainty of the time transfer link between two GNSS time and frequency transfer receivers should be less than 5.5 ns.

B. Propagation Errors

The standard uncertainty components due to ionospheric and tropospheric errors are 0.3 ns and 0.7 ns respectively which are valid for baselines up to 5000 km[4]

C. Delay Error of Cables and Converters

Evaluated by type B method, the standard uncertainty component due to the cables and the converters calibrated by VNA could be less than 0.1 ns.

D. Combined Uncertainty and Its Expension

The combined uncertainty u_c and its expension U_c can be obtained by (1) and (2) in table I.

$$u_c = \sqrt{{u_A}^2 + {u_B}^2} \tag{1}$$

$$U_c = k \cdot u_c \tag{2}$$

TABLE I. Uncertainty Budget

Source	Type	Uncertainty (ns)	
		C/A code	*P3 code*
Measurement jitter of GNSS time transfer link between two receivers	A	1.5	0.7
Uncertainty for calibration of GNSS time transfer link	B	5.5	5.5
Propagation errors(including ionospheric and tropospheric error for GNSS time transfer link)	B	0.8	0.8
Delay error of cables and converters for one GNSS time and frequency transfer receiver	B	0.1	0.1
Delay error of cables and converters for the other GNSS time and frequency transfer receiver	B	0.1	0.1
Combined uncertainty		5.8	5.7
Expanded uncertainty (k=2)		11.6	11.4

V. Conclusion and Prospect

The combined uncertainty of about 6 ns for time calibration and the corresponding uncertainty of about 2e-14 averaging one week for frequency calibration could be obtained. Preliminarily the time and frequency accuracy of better than 10 ns and 1e-13 separately averaging one day for NIMDO could be realized, and the time and frequency stability averaging one day could be better than 5 ns and 3e-14 respectively. Soon we would improve the steering algorithm and lay up five NIMTFGNSS-1 receivers at four different cities (Urumchi, Guiyang, Haerbin, and Beijing) in China to verify the effects more deeply in the longer baseline. In the near future, using GNSS real-time or near real-time precise ephemeris products, GNSS carrier phase time and frequency transfer will be studied and applied in RTRC and NIMDO to improve their performances.

Acknowledgements:

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