Real Time Monitoring of IGS Products within the RTIGS Network

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1 Introduction

Since the boom in mobile telecommunications allows Internet access for anyone anywhere at any time, this medium has also become an alternative method for transmitting GNSS data streams. Since 3 years the IGS (International GNSS Service) Real-Time Working Group exploits the options offered by the World Wide Web to disseminate raw observation data of a subset of stations of the IGS network as well as ephemeris and surface meteorological data. This observation data can be used for a real time integrity monitoring of the GNSS-Broadcast orbits as well as for the IGS predicted orbits (Ultra Rapid Orbits). These satellite ephemeris demonstrate significantly higher accuracy (~10 cm) than the broadcast orbits (~ 2m), but carry the risk of individual, recurring outliers.
This paper highlights the functionality of a software-tool for integrity monitoring. The program "RTR- Control" has been developed at the Institute of Geodesy and Geophysics, TU-Vienna, supported by the IGS Real-Time Working Group. According to the recommendations of the IGS Workshop 2004 in Bern the "IGS should set up an integrity monitoring of IGS Real Time (IGU) products". This work can be interpreted as a first prototype under development.

2 How "RTR- Control" works

The input data for the Program are Code Pseudoranges (P1 and P2) measured at any permanent station in the global RTIGS network. The data is received via the RTIGS- datastream. "RTR-control" automatically loads the most recent IGU- orbits every 6 hours just after they are published. This procedure ensures that always the most current orbits are used for calculations. By means of the satellite coordinates and given station coordinates geometric ranges are computed. The comparison of the calculated with the measured and corrected pseudoranges can be used for the diagnose of incorrectly predicted satellite- orbits and clocks as well as for the detection of multi-path distorted pseudoranges. This diagnose is done epochwise by an least squares adjustment (by estimating receiver- and satellite clock corrections and pseudorange residuals every 15 seconds). The pseudorange residuals and clock corrections are automatically stored as textfiles and delivered in permanently updated figures.
The principal computations of this real- time control comprise the reduction of so called PR-differences (PRd) and subsequently the least squares adjustment. They are done within the following 4 steps.

- Calculation of the Receiver- Satellite Ranges
- Correction of the measured Code Pseudoranges
- Estimation of approximate receiver- and satellite clock correction
- Least Squares Adjustment (PRd, Clock Corrections)

2.1 Calculation of Receiver Satellite Range

$$CR_k^j = \sqrt{\left(Xe_k - Xs^j\right)^2 + \left(Ye_k - Ys^j\right)^2 \left(Ze_k - Zs^j\right)^2}$$

$CR_k^j =$ **calculated range from receiver** k **to satellite** j

$Xe_k, Xe_k, Xe_k =$ **known coordinates of receiver** k

$Xs_j, Xs_j, Xs_j =$ **coordinates of satellite** j **from IGU - Orbits**

2.2 Correction of measured Pseudoranges

$$PRc_k^j = PR\_L3_k^j - dtrop_k^j + drel_k^j * c$$

$PRc_k^j =$ **corrected pseudorange from receiver** k **to satellite** j

$PR\_L3_k^j =$ **L3 linear combined code pseudorange from receiver** k **to satellite** j

$dtrop_k^j =$ **tropospheric correction of** $PR\_L3_k^j$ **estimated with the Saastamoinen model**

$drel_k^j =$ **calculated relativistic correction of** $PR\_L3_k^j$

$c =$ **speed of light**

2.3 Calculation of the approximate Receiver- and Satellite Clock Correction

The satellite clock correction can directly be interpolated from the clock predictions of the IGU orbits, wheras the receiver clock corrections have to be calculated seperately in 2 steps.

Step 3a:

$$PRda_k^j = PRc_k^j + SCCa^j - CR_k^j$$

$PRda_k^j =$ **auxiliary pseudorange - difference from receiver** k **to satellite** j

$SCCa^j =$ **approximate value of the clock correction for satellite** j **from IGU - Orbits**

Step 3b:

$$RCCa_k = \frac{\sum_{i=1}^{n} \frac{PRda_k^n}{c}}{n}$$

$RCCa_k =$ **approximate clock correction for receiver** k

$n =$ **number of visible satellites**

2.4 Least Square Adjustment

Observation Equations:

$$PRd_k^j = PRc_k^j - CR_k^j - l_0$$

$PRd_k^j =$ **pseudorange - difference form receiver** k **to satellite** j

Approximate Values:

$$l_0 = \left(RCCa_k - SCCa^j\right) * c$$

The parameters of the adjustment are the Clock Correction improvements, thus the results represent the corrected receiver clock (see Fig. 1) and the corrected satellite clock, rid of clock prediction model errors contained in the IGU- orbits.
The remaining pseudorange residuals represent the range errors of the measured pseudoranges, including multipath effects, satellite orbit errors and noise, but no satellite clock prediction errors.

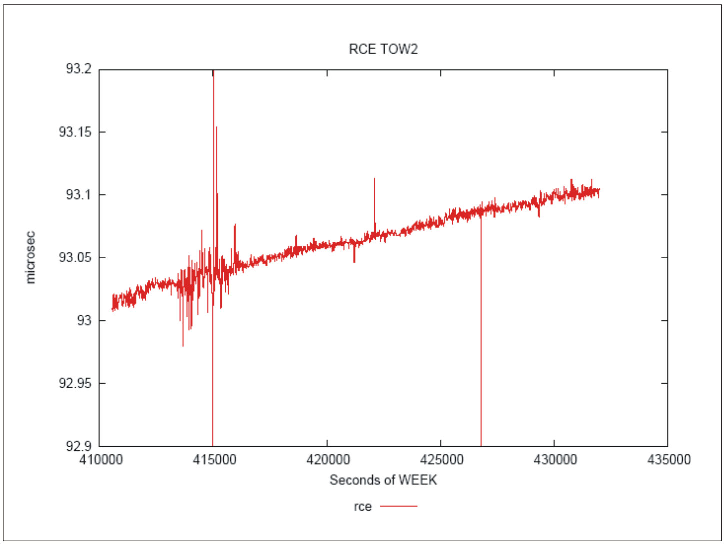

Fig. 1: Receiver Clock Correction Station TOW2

3 Network and Test

3.1 Network

“RTR- Control” uses a subset of 35 Stations of the RTIGS- network spreaded all over the world. The presented results were recorded on Thursday, 16th of March, 2006. The used orbits are IGU13674_12.sp3 and IGU13674_18.sp3. The change to more recent ephemeris occured at 425173s (=22:06 UTC) of day 4 in GPS- week 1367. During this test period just 24 stations sparsely distributed (marked in red, Fig. 2) transmitted data.

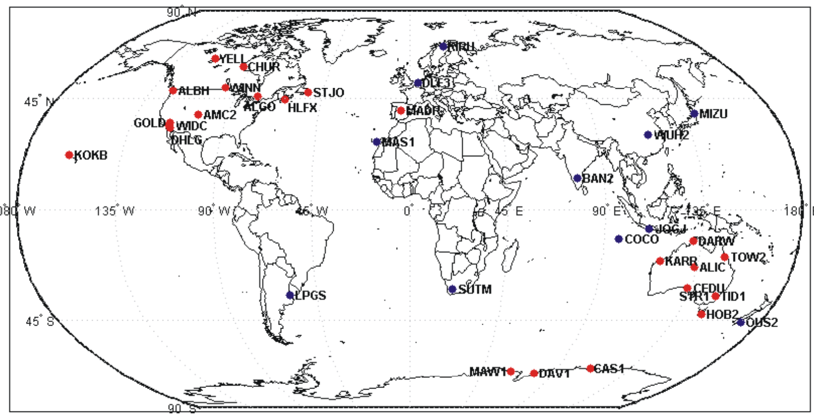

Fig. 2: RTIGS- Stations in use

3.2 General Results

Fig.3 shows in the lower plot the differences of the calculated satellite clock corrections to the IGU- clock predictions and in the upper box the pseudorange residuals (the arrangement of the graphics in Fig. 5, 6 and 8 follow the same order) of satellite PRN5. The data gaps demonstrate the intermittent poor density of the network in case of one organisation submits no data e.g., no data from Australia. Without a better network distribution it's not possible to monitor all satellites permanently.

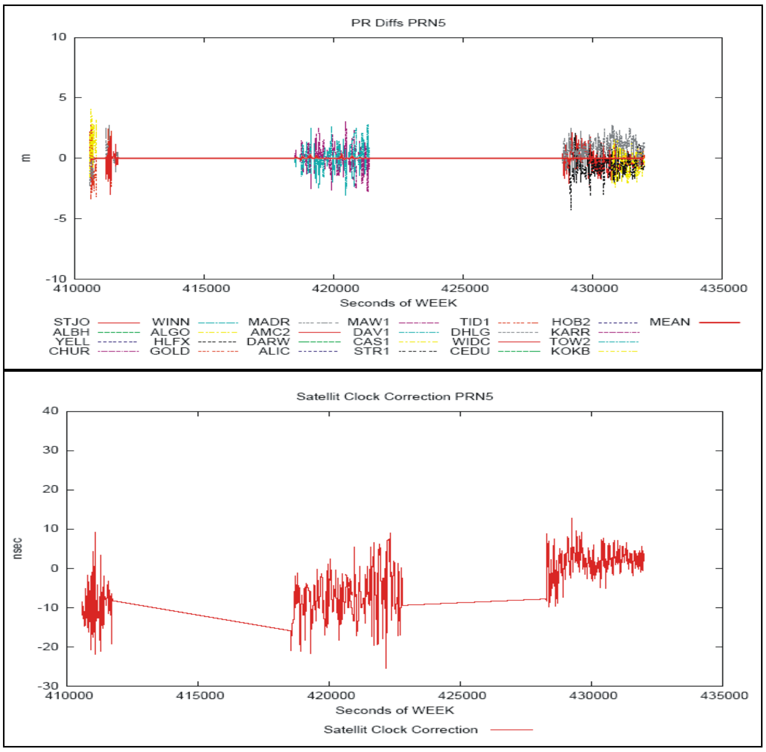

Fig. 3: Pseudorange Residuals and Satellite Clock Correction of PRN 5

In Fig. 4 the pseudorange residuals for all satellites visible at stations WINN and ALGO are presented. It becomes obvious that the behaviour of the pseudorange residuals heavily depends on the receiver used.

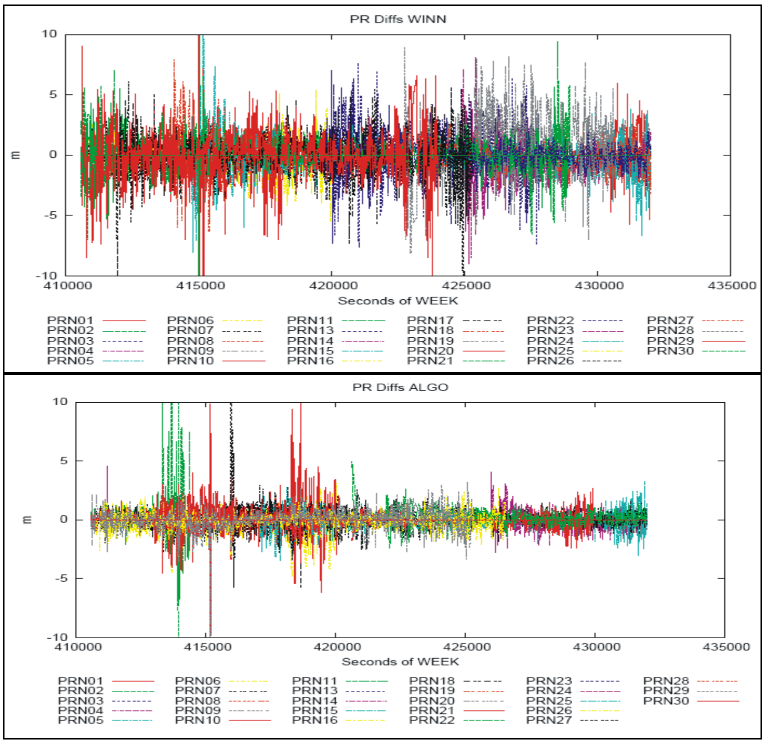

Fig. 4: Pseudorange Residuals at Station WINN and ALGO

4 Particular Results

Fig. 5 and 6 show the differences of the calculated satellite clocks to the predicted IGU- clocks and corresponding pseudorange residuals for satellites PRN1 and PRN25. Fig. 7 presents the a posteriori calculated differences between the predicted IGU- clocks and the observed IGR- clocks.
The trend of the satellite clocks estimated in real time by “RTR- Control” correspond for both satellites quiet well with the observed clocks (e.g. see Fig. 5). For all satellites the jump in the time series representing the change to more recent IGU orbits can easily be figured out. Furthermore the permanent negative respectively positive sign of the clock differences of satellite PRN1 and PRN25 can bee verified in both graphics.

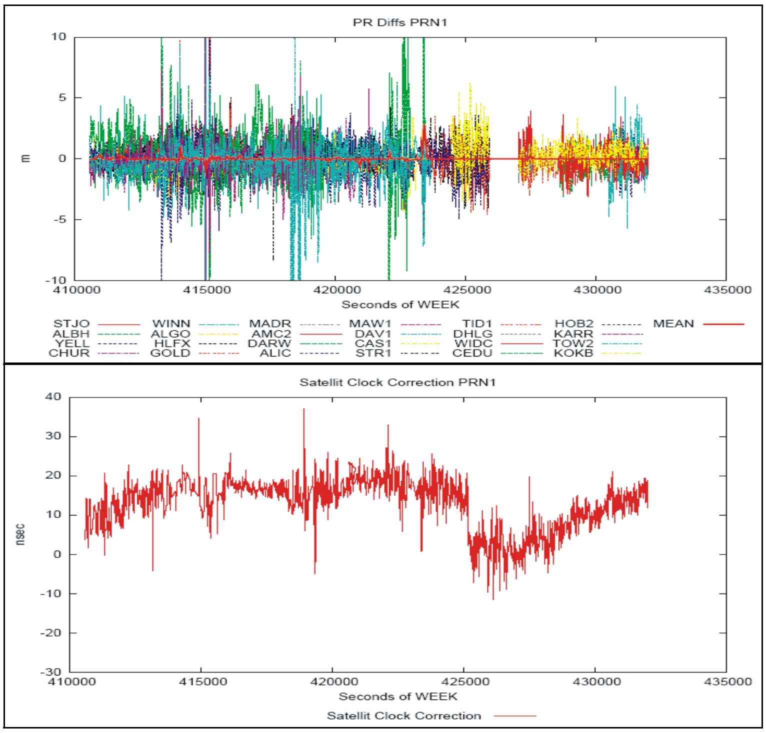

Fig. 5: Pseudorange Residuals and Satellite Clock Correction of PRN 1

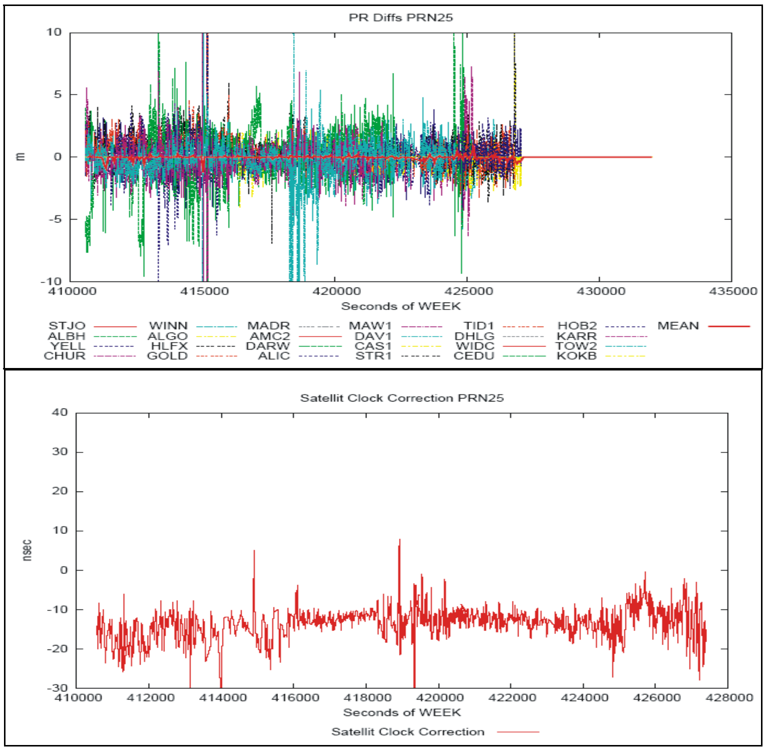

Fig. 6: Pseudorange Residuals and Satellite Clock Correction of PRN 25

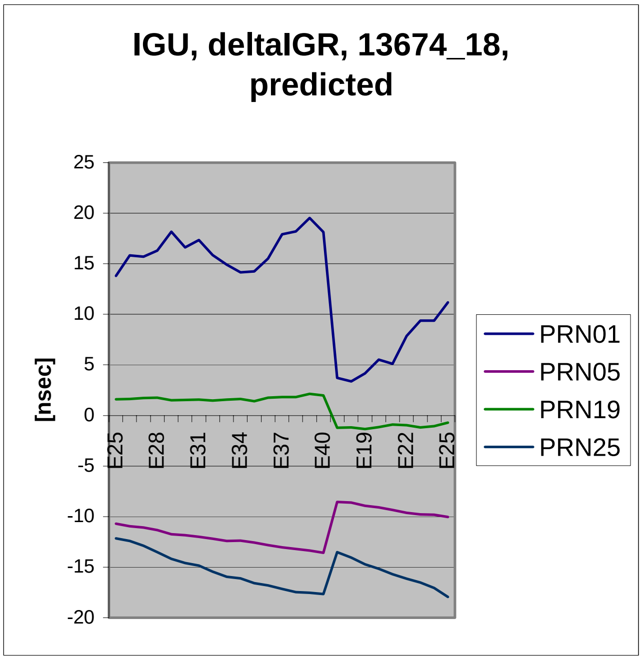

Fig. 7: Differences between IGU- and IGR- Clock Estimation

Fig. 8 shows the results obtained for satellite PRN19. Its ephemeris were artificially adulturated by 20 m in X, Y and Z.

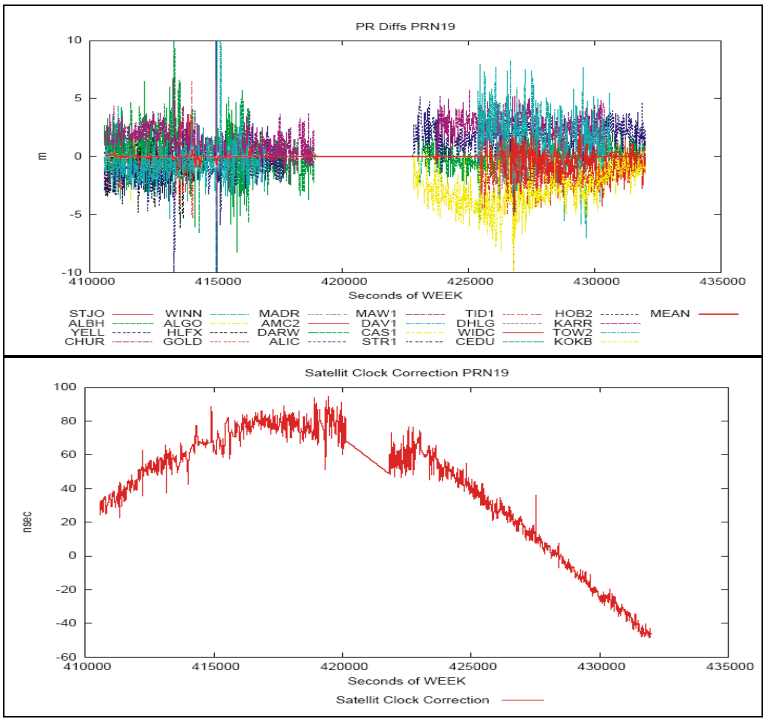

Fig. 8 Pseudorange Residuals and Satellite Clock Correction of PRN 19

It is clearly visible that this huge orbit error mainly shows up in a far too high clock correction in comparison to the a posteriori calculated clock correction presented in Fig. 7. Nevertheless the orbit error can also be noticed in the noisy behaviour of the pseudorange residuals calculated for the different stations.
Fig. 9 demonstrates that single multipath adulturated pseudoranges can be detected in the pseudorange residual plot. This artificial “bad measurements” do not deteriorate the adjustment and they are also fortunately not covered by this process.

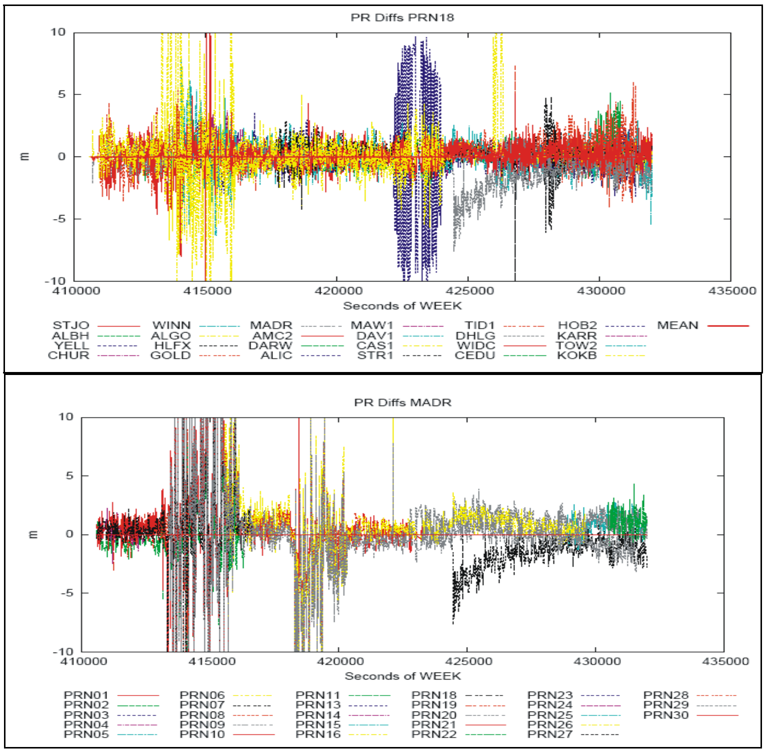

Fig. 9: Pseudorange Residuals of PRN 18 and at Station MADR

5 Summary

The performed tests show, that “RTR- Control” can be used for detecting probably erroneous satellite clock predictions. The time series of the clock differences between IGU- predictions and IGR observations and the clock differences computed by the program show the same trend and absolute values. Orbit errors mainly propagate into the satellite clock corrections but also show up in the pseudorange errors. Multipath distorted pseudoranges are detected in the pseudorange residuals and do not effect the receiver- or satellite clock estimation.
Ongoing tests show that more pseudorange measurements to all satellites are needed in order to get better and more reliable results. This means the distribution of the network has to be improved in order to get more stable results for all satellites over most of the time.
Besides the improvement of the pseudorange correction the next steps in the development of the program are a better seperation of satellite orbit-, satellite clock- and ranging errors as well as an estimation of the direction of the orbit error (vector). In future also phase measurements shall become input data of the control process.

Operated in processing facilities of RTK station networks “RTR- Control” prevents that observation data of mismodeled satellites is further used for the calculation of range-corrections which are passed to the RTK users within the network. Thus the user group interested in a rigorous integrity monitoring comprises on the one hand IGS itself to qualify the issued orbital data and on and the other hand authorities and companies operating such Real Time GNSS station networks.