GPS Timing Performance

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Abstract

GPS signals provide the world with Coordinated Universal Time (UTC) as realized through UTC(USNO), which is UTC's realization by the U.S. Naval Observatory (USNO) [1]. Interoperability with Galileo, and perhaps someday with other Global Navigation Satellite Systems (GNSS), is to be established through transmission of the differences between the GNSS system times. This paper describes the performance of the GPS system, which is constantly being improved.

1. Introduction

Time is available on all GPS satellites via the L1 signal, and an increasing number of satellites are now broadcasting publicly available modernized L2C and L5 signals as well. Further improvements are expected as new satellite clocks are launched. Also, although not the subject of this paper, user equipment and data processing is also becoming more efficient in every way.

GPS Time is a navigational timescale which, because timing information is uploaded to satellites asynchronously, does not include leap seconds and is offset from International Atomic Time (TAI) by 19 seconds. Its performance and statistics (always modulo 1 second) are presented here, but for all non-navigational uses it is best to apply the corrections in the GPS navigation message's subframe 4, page 18 or in the modernized civil navigation message type 33 so as to obtain UTC. The formal and correct expression for UTC derived from GPS is "GPS's delivered prediction of UTC(USNO)", however we shall simply refer to it as UTC(USNO) via GPS. From a statistical point of view, there are many ways to measure GPS timing performance as a delivered product. If one is interested in obtaining UTC, the best measurement metric would likely be the root mean square (RMS), as a function of averaging time. In contrast, GPS users who wish to obtain frequency could be interested in the RMS of the frequency, but might also find the Allan variance to be a useful measure of performance.

Although this paper is concerned with time as broadcast by GPS, we note that user equipment could provide limitations on its accessibility. Single-frequency GPS receivers will be unable to correct for ionosphere delay below the 10 ns level, whereas dual-frequency receivers can directly measure the delay so as to apply a more accurate correction. In addition, users who have access to precise corrections for GPS orbits and clocks will benefit from their superiority over the broadcast corrections [2]. Most importantly, receivers that can access interoperable GNSS systems will benefit from the additional satellites, and in certain situations markedly so.

2. Current Performance Under Optimal Conditions

As a time-delivery system, GPS is characterized by the deviations of its corrected clocks from UTC(USNO), and in this paper we describe the performance of the average of those corrected clocks.. Many of the effects that mask GPS performance can be corrected using International GNSS Service (IGS) products. From the IGS and its cooperating sites, one can download data to correct errors related to clocks, orbits, troposphere, and ionosphere. Tidal and Earth Orientation information can also be applied. The user seeking to realize maximal precision and accuracy should also take care that the receiver is well-calibrated, the antenna environment is low-multipath, and temperature/humidity fluctuations are stabilized. Figure 1 shows the precision available from the GPS constellation average, as measured at the USNO, after application of all the above corrections. In some cases input from the GPS Master Control Station's Kalman Filter was used, instead of corresponding IGS values. Figure 2 describes the frequency-delivery of GPS, for GPS Time and UTC(USNO) via GPS, each as measured by the Allan deviation and the RMS. Figures 3 and 4 provide a historical perspective on GPS's timing performance. Figure 3 shows the actual deviations of daily averages since 2002, while Figure 4 shows how the performance has improved over the last two decades.

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14. ABSTRACT
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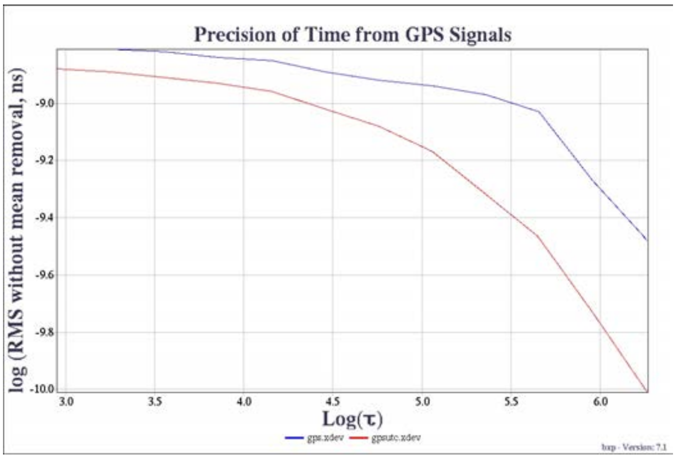

Figure 1. Timing RMS in nanosecond of the observable GPS constellation average as a function of averaging time in seconds over the last year, as measured at the USNO. The upper curve provides the performance of GPS Time and the lower curve is for UTC(USNO) via GPS.

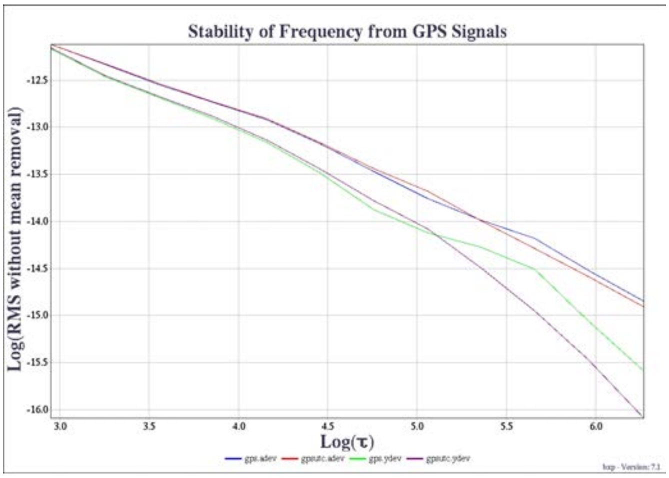

Figure 2. Frequency stability of the observable GPS constellation average, in nanoseconds, as a function of averaging time in seconds. The upper two curves are for the Allan Deviation, and the lower two are the RMS. The plotted differences between the frequencies of GPS Time and UTC(USNO) via GPS are insignificant.

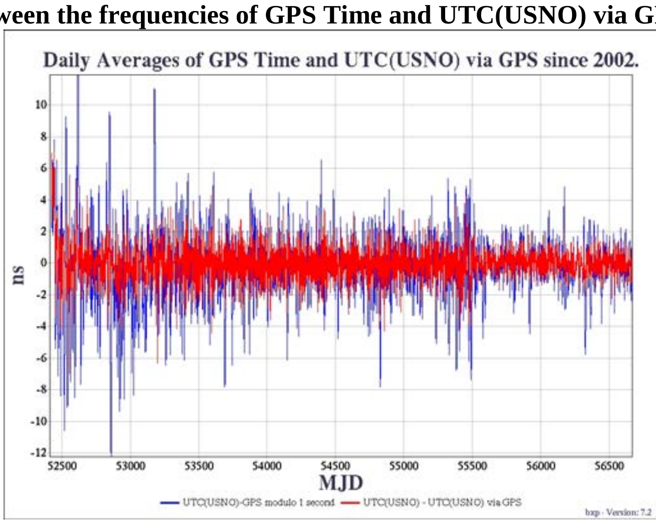

Figure 3. Daily averages of GPS Time (blue) and UTC(USNO) via GPS (red), since 2002. The reference (truth standard) is UTC(USNO) as realized by an electronic signal at the USNO.

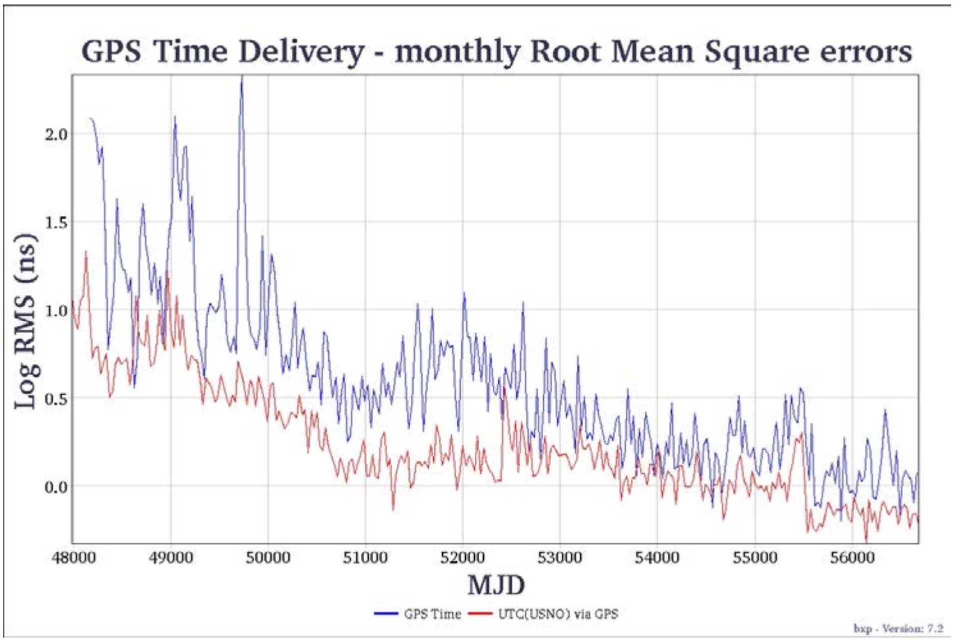

Figure 4. Monthly standard deviations in GPS Time and UTC(USNO), 1987-2013.

3. Interoperability

As a matter of American policy, USNO is participating in the exchange of timing information with the Galileo precise-time providers. The current scheme includes use of Two Way Satellite Time Transfer (TWSTT) [3] links between USNO and the Physikalisch-Technische Bundesanstalt (PTB), and between PTB and the Precise Time Facilities (PTF) - only one of which is online as of this writing. This provides the difference between UTC(USNO) and the master clocks. When supplemented by locally measured GPS-UTC(USNO) and Galileo-PTF time, the difference between GPS and Galileo times is obtained. This is termed the Galileo-GPS Time Offset (GGTO), and it will be Type 35 in the GPS CNAV message. Knowledge of the GGTO makes it possible for a properly programmed and calibrated GNSS receiver to combine data from different GNSS for an improved solution. In urban canyons and other areas of restricted sky coverage it could enable a satisfactory solution where none was possible before.

A key issue for interoperability is to understand and be able to correct for the biases between all signals, which for each user depend upon the satellite, the individual receiver, and the receiver's operating configuration [4-7]. Figure 5 shows how they can vary over time.

4. Conclusion

The time and frequency transfer of GPS, though perhaps in some ways masked by current user equipment and other sources of error, is improving. Improved user equipment will enable the user to access the full capabilities of GPS.

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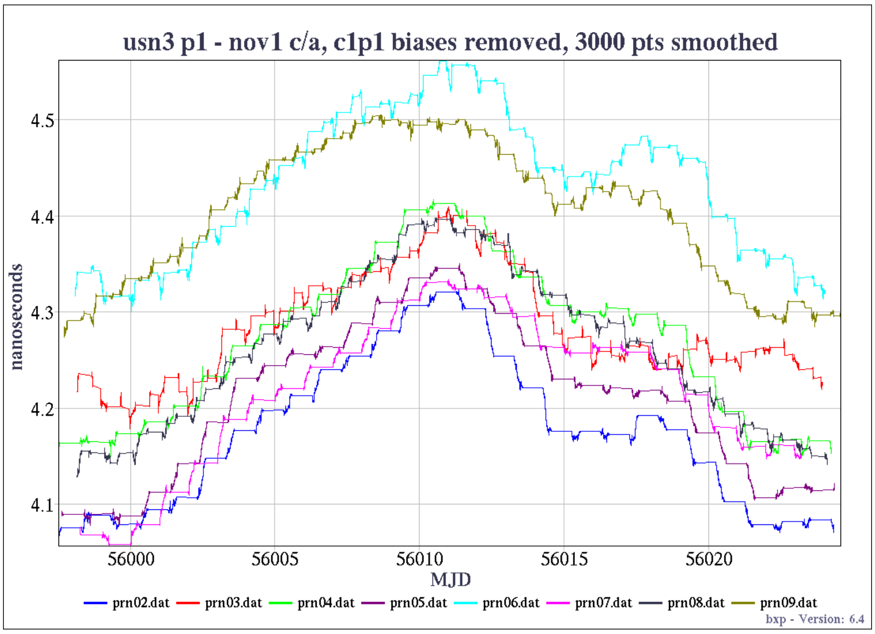

Figure 5. The remaining difference between two receivers' data for 8 individual satellites, after applying the standard C-P bias-correction programs to the C1-producing receiver. The overall bias of approximately 4.2 ns could be zeroed using a receiver calibration.

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