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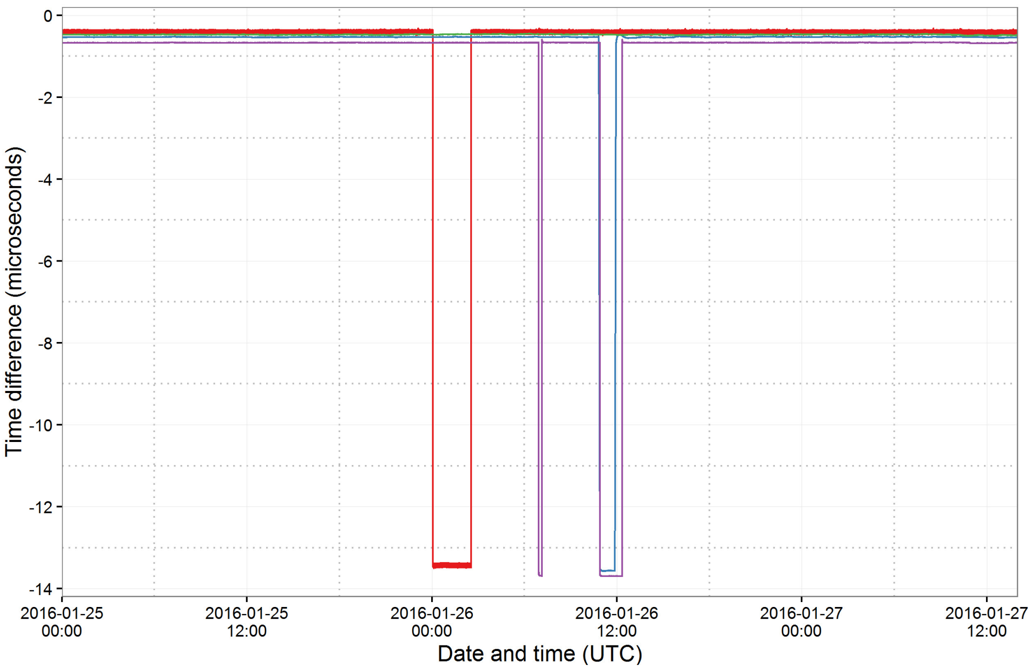

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Abstract

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Abstract
On Tuesday, January 26th 2016 Aalto University Metsähovi Radio Observatory discovered that three out of its four GPS receivers on-site (used for monitoring the performance of four on-site hydrogen (H) maser atomic clocks) performed abrupt 13.0 microsecond time jumps in their "1pps" (one pulse per second) time synchronization outputs. The disruptions lasted for approximately 12 hours during which different GPS receiver units outputted erroneous time signal at different times, preventing their use for microsecond-level time synchronization. The event was later acknowledged by the 2nd Space Operations Squadron at the 50th Space Wing, Schriever Air Force Base, Colorado, USA, as an erroneous time correction parameter upload to GPS satellites.

Keywords radio astronomy, global positioning system, GPS, atomic clocks, timing, satellites, satellite navigation

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Aalto University Metsähovi Radio Observatory, Finland

Abstract

On Tuesday, January 26th 2016 Aalto University Metsähovi Radio Observatory discovered that three out of its four GPS receivers on-site (used for monitoring the performance of four on-site hydrogen (H) maser atomic clocks) performed abrupt 13.0 microsecond time jumps in their "1pps" (one pulse per second) time synchronization outputs. The disruptions lasted for approximately 12 hours during which different GPS receiver units outputted erroneous time signal at different times, preventing their use for microsecond-level time synchronization. The event was later acknowledged by the 2nd Space Operations Squadron at the 50th Space Wing, Schriever Air Force Base, Colorado, USA, as an erroneous time correction parameter upload to GPS satellites.

Contents

1 Introduction

Aalto University Metsähovi Radio Observatory maintains four hydrogen (H) maser type atomic clocks on-site to regularly perform global very long baseline interferometry (VLBI) radio astronomy observations together with VLBI observatory networks such as the European VLBI Network (EVN), International VLBI Service (IVS), and Global mm-VLBI Array (GMVA). The performance of the H masers is monitored by comparing their "1pps" (one pulse per second) time synchronization outputs to similar 1pps outputs of four different time-recovery GPS receivers. A dedicated multi-channel time difference counter (called "clodi", originally designed and manufactured at Metsähovi[1]) is triggered at every one-second 1pps pulse of the primary H maser atomic clock to measure the time difference between the primary H maser, the secondary H maser, and four GPS receivers. The setup is illustrated in Figure 1.

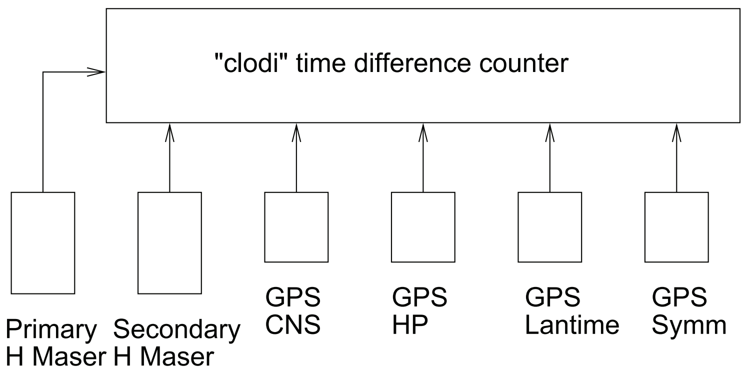

Figure 1. H maser monitoring at Metsähovi Radio Observatory.

The time difference values are logged and stored in Metsähovi long-term data archive in perpetual daily UTC time-tagged plain text files. Once every hour, the automated "Nagios"[2] infrastructure monitoring system performs checks on this time difference data, with the aim to detect failures in Metsähovi H maser atomic clocks. The checks (until 26-Jan-2016) used to send alarm email messages to technical personnel if time difference is

[1]Koski, M.: A design of a comparing system for precise clocks (in Finnish), Bachelor's thesis, April 2003. ("Tarkkojen kellojen vertailujärjestelmän kehittely", insinöörityö, Helsingin ammattikorkeakoulu Stadia.)

[2]`https://www.nagios.org/`

abnormally large, implicitly assuming that GPS time is correct and that it must be the H maser clocks which are failing.

2 GPS Time Jumps on the 26th of January

On Tuesday, January 26th 2016 the automated Nagios alarm triggered and warned that Metsähovi H maser atomic clock time is off by 13.0 microseconds. After inspecting "clodi"-based time comparison data it was all too clear that both the primary and the secondary H maser clock were keeping the correct time without any abrupt jumps. Instead, three out of four Metsähovi GPS receivers were randomly outputting time which was 13.0 microseconds off. All the receivers were not simultaneously outputting wrong time, instead, different receiver models were off at different times, as depicted in Figure 2.

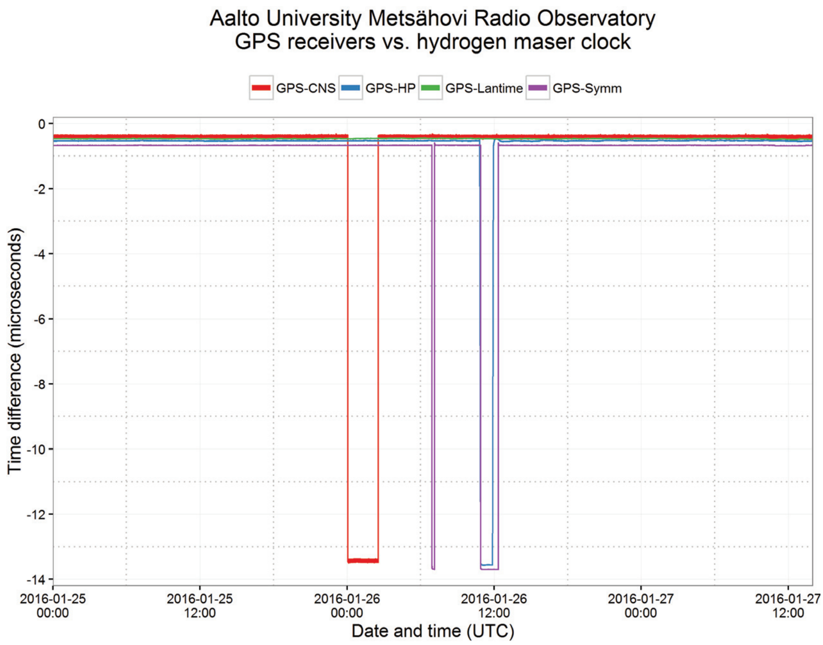

Figure 2. Time difference between Metsähovi H maser and four different GPS receivers.

We contacted immediately Metsähovi global VLBI partner radio observatories and asked if they are also observing this phenomenon in their H maser clock monitoring data. Within hours, positive confirmations started to arrive back.

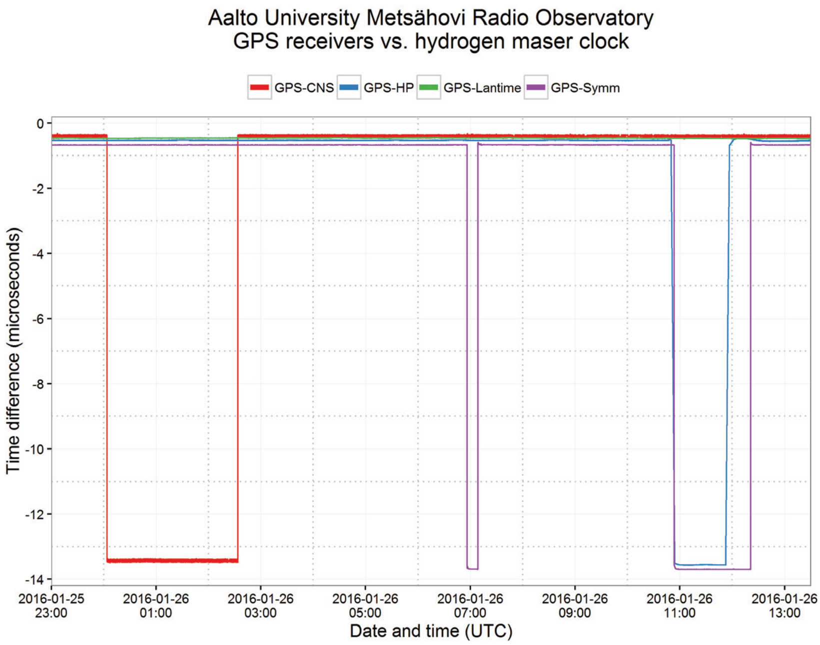

Figure 3. A detailed plot of the time difference between Metsähovi H maser and four different GPS receivers, for the duration of disruption only.

3 Aftermath on the 27th of January

The next day, on Wednesday 27th, the erroneous 13.0 microsecond jumps in GPS time signal seemed to have ceased at Metsähovi. The last time jump observed ended on 26-Jan-2016 around 12:00 UTC time. As the first time jump was detected on 26-Jan-2016 around 00:00 UTC time, the total duration of the global GPS timing disruption was approximately 12 hours.

The truly global nature of the problem and its duration was confirmed by the majority of global VLBI radio observatories. Over night, GPS time jump phenomena were seen by Metsähovi collaboration observatories such as Arecibo in Puerto Rico, the geodetic VLBI observatory of Ny Ålesund in Svalbarden, three radio telescopes in China, part of NRAO VLA and VLBA telescopes in USA, Jodrell Bank in United Kingdom, ATCA in Australia and Max-Planck Institut für Radioastronomie in Effelsberg, Germany. In Yebes, Spain no abrupt time jumps were detected, only minor deviations from the usual time difference patterns. Judging from the reports arriving from all around the globe, the problem was clearly confirmed being truly global.

At this point of time, the only public report of GPS problems at the US "NAVCEN" Navigation Center was that one of the GPS satellites was malfunctioning and it was decommissioned.[3]

The timeline described in the report did not fit well with observed GPS time disturbances. The satellite “PRN32/SVN23”, one of the oldest in the current GPS constellation, over 25 years, had failed already on 25-Jan-2016 at 15:36 UTC and it was remotely shut down and decommissioned on 25-Jan-2016 at 22:00 UTC. At that time there were no anomalies in Metsähovi GPS monitoring system, as can be seen in Figure 2.

The first time jump appears in Metsähovi monitoring only after two hours after the reported decommissioning of the satellite, and the time jumps continue from thereon for approximately 12 hours, until Tuesday 26th at 12:00 UTC.

One international GPS news web site mentioned that there has been reports of GPS timing problems and that such issues should always be reported to the US NAVCEN.[4]

4 Confirmed Reason

The confirmed reason behind these GPS time jump was that some of the satellites were sending wrong UTC time correction parameters to GPS receivers. The official US press release can be found at:

`http://www.navcen.uscg.gov/pdf/gps/`
`AirForceOfficialPressRelease.pdf`

In the press release (a copy of it can be found in Appendix A), the Master Control Station (MCS) of the GPS system at the 2nd Space Operations Squadron at the 50th Space Wing, Schriever Air Force Base, Colorado, USA describes that the offending parameters were uploaded to the satellites sending so-called “legacy L-band” signal. This 1575.42 MHz signal is usually called the “L1 Coarse/Acquisition” or “L1 C/A” and it still establishes the foundation of GPS civilian use and is the basis of common GPS navigation and timing applications. It took some time, however, for this official US press release to reach Metsähovi. Although the official press release was sent out approximately 14 hours after the quoted problem resolution time (at 13:10 UTC on 27-Jan-2016), it was only sent to the members of the Civil Global Positioning System Service Interface Committee (CGSIC) using an email distribution list targeted to the members

[3] `http://www.navcen.uscg.gov/?Do=gpsShowNanu&num=2016008`

[4] `http://gpsworld.com/report-gps-timing-issues-to-navcen/`

of CGSIC only. News items mentioning the anomaly and the press release appeared on the official GPS web sites[5] only after the weekend, on Monday and Tuesday of the next week.

Another interesting aspect in the error description of the timing problem is that according to the press release it “only affected the time on legacy L-band signals”. However, according to the GPS system description, all the satellites are capable of sending and they indeed send the legacy ”L1 C/A” signal. If all satellites would have sent the same erroneous parameter (13.0 microseconds off), why did not all the GPS receivers jump at the same time? According to global observations by Metsähovi and other radio observatories, the jumps have occurred in random and thus it is clear that only a subset of satellites has been sending erroneous UTC time correction information.

5 Global Impact of GPS Time Disruption

A deviation of 13 microseconds in GPS timing signals may not seem like a large error but it was enough to severely disturb the digital DAB radio broadcats of BBC in the UK.[6]

By system design, DAB transmitters rely on GPS timing signals to be in synch to the microsecond level so that adjacent transmitters can send the digital transmission stream in synch. When out of synch by as much as 13 microseconds, adjacent DAB transmitters start to interfere with each other and prevent decoding of the bit streams from received antenna signals.

Many providers of GPS-based timing systems and timing technology also reported “chaos” as their customers flooded their support services with reports of GPS equipment setting off alarms of time being unexpectedly off.[7] The UK-based Chronos Technology Ltd and German Meinberg GmbH were among the first to publicly describe the anomaly and Meinberg was the first to present a fairly accurate description of the root cause of the incident.[8]

[5] http://www.gps.gov/, http://www.navcen.uscg.gov/.

[6] http://www.bbc.com//news/technology-35463347

[7] http://www.bbc.com/news/technology-35491962

[8] https://www.meinbergglobal.com/english/news/global-gps-time-anomaly-on-tue-jan-26th.htm

6 Improvements in Metsähovi GPS Monitoring System

Since the original version of the hourly automated Nagios check which was active on 26-Jan-2016 targeted detecting problems with the Metsähovi primary H maser atomic clock and assumed that GPS time would be correct, it only checked one time difference value between the primary H maser 1pps output and the primary GPS receiver ("GPS-Symm" in illustrations) 1pps output. It did not make use of other three secondary/redundant GPS receivers. Since the first time jump occurred in one of the secondary GPS receivers ("GPS-CNS"), it went undetected by the original Nagios check script.

The Nagios H maser vs. GPS check script was thus later augmented to check all the time difference values of Metsähovi primary H maser to all four GPS receivers, and if any of those show a deviance of more than +/- 1 microseconds within the last hour, then an alarm email will be sent to Metsähovi technical personnel.

7 Conclusions

Despite the GPS timing error magnitude in this particular incident was only 13.0 microseconds, it is frightening to realize that larger or more unpredictable timing errors could appear in the GPS system in the future, with similar ease at which this one occurred. GPS timing signals are being increasingly used to automatically synchronize spatially distributed systems such as radio networks. The more prevalent GPS use becomes, the more dependent our society and its functions become on the uninterrupted correctness of GPS timing and location information.

Appendix A: The Official US Air Force Press Release

A copy of the press release[9] on 17-Feb-2016 is shown below.

AIR FORCE OFFICIAL PRESS RELEASE - GPS GROUND SYSTEM ANOMALY

JAN 27, 2016

On 26 January at 12:49 a.m. MST, the 2nd Space Operations Squadron at the 50th Space Wing, Schriever Air Force Base, Colo., verified users were experiencing GPS timing issues. Further investigation revealed an issue in the Global Positioning System ground software which only affected the time on legacy L-band signals. This change occurred when the oldest vehicle, SVN 23, was removed from the constellation. While the core navigation systems were working normally, the coordinated universal time timing signal was off by 13 microseconds which exceeded the design specifications. The issue was resolved at 6:10 a.m. MST, however global users may have experienced GPS timing issues for several hours. U.S. Strategic Command's Commercial Integration Cell, operating out of the Joint Space Operations Center, effectively served as the portal to determine the scope of commercial user impacts. Additionally, the Joint Space Operations Center at Vandenberg AFB has not received any reports of issues with GPS-aided munitions, and has determined that the timing error is not attributable to any type of outside interference such as jamming or spoofing. Operator procedures were modified to preclude a repeat of this issue until the ground system software is corrected, and the 50th Space Wing will conduct an Operational Review Board to review procedures and impacts on users. Commercial and civil users who experienced impacts can contact the U.S. Coast Guard Navigation Center at (703) 313-5900.

[9] http://www.navcen.uscg.gov/pdf/gps/AirForceOfficialPressRelease.pdf

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