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Leap second

A **leap second** is a one-second adjustment that is occasionally applied to civil time Coordinated Universal Time (UTC) to keep it close to the mean solar time at Greenwich, in spite of the Earth's rotation slowdown and irregularities. UTC was introduced on 1972 January 1st, initially with a 10 second lag behind International Atomic Time (TAI). Since that date, 27 leap seconds have been inserted, the most recent on December 31, 2016 at 23:59:60 UTC, so in 2018, UTC lags behind TAI by an offset of 37 seconds.[1]

Screenshot of the UTC clock from time.gov (https://time.gov/) during the leap second on December 31, 2016. In the USA, the leap second took place at 19:00 local time on the East Coast, at 16:00 local time on the West Coast, and at 14:00 local time in Hawaii.

The UTC time standard, which is widely used for international timekeeping and as the reference for civil time in most countries, uses the international system (SI) definition of the second. The UTC second has been calibrated with atomic clock on the duration of the Earth's mean day of the astronomical year 1900. Because the rotation of the Earth has since further slowed down, the duration of today's mean solar day is longer (by roughly 0.001 seconds) than 24 SI hours (86,400 SI seconds). UTC would step ahead of solar time and need adjustment even if the Earth's rotation remained constant in the future. Therefore, if the UTC day were defined as precisely 86,400 SI seconds, the UTC time-of-day would slowly drift apart from that of solar-based standards, such as Greenwich Mean Time (GMT) and its successor UT1. The point on the Earth's equator where the sun culminates at 12:00:00 UTC would wander to the East by some 300 m each year. The leap second compensates for this drift, by occasionally scheduling a UTC day with 86,401 or (in principle) 86,399 SI seconds.

When it occurs, a positive leap second is inserted between second 23:59:59 of a chosen UTC calendar date and second 00:00:00 of the following date. The definition of UTC states that the last day of December and June are preferred, with the last day of March or September as second preference, and the last day of any other month as third preference.[2] All leap seconds (as of 2017) have been scheduled for either June 30 or December 31. The extra second is displayed on UTC clocks as 23:59:60. On clocks that display local time tied to UTC, the leap second may be inserted at the end of some other hour (or half-hour or quarter-hour), depending on the local time zone. A negative leap second would suppress second 23:59:59 of the last day of a chosen month, so that second 23:59:58 of that date would be followed immediately by second 00:00:00 of the following date. Since the introduction of leap seconds, the mean solar day has outpaced UTC only for very brief periods, and has not triggered a negative leap second.

Because the Earth's rotation speed varies in response to climatic and geological events,[3] UTC leap seconds are irregularly spaced and unpredictable. Insertion of each UTC leap second is usually decided about six months in advance by the International Earth Rotation and Reference Systems Service (IERS), when needed to ensure that the difference between the UTC and UT1 readings will never exceed 0.9 seconds.[4][5]

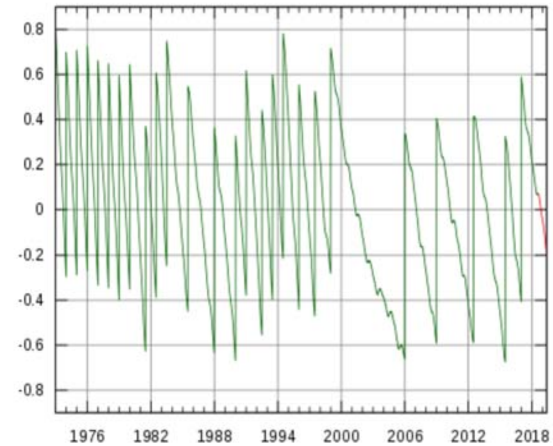
Contents

History

About 140 AD, Ptolemy, the Alexandrian astronomer, sexagesimally subdivided both the mean solar day and the true solar day to at least six places after the sexagesimal point, and he used simple fractions of both the equinoctial hour and the seasonal hour, none of which resemble the modern second.[6] Muslim scholars, including al-Biruni in 1000, subdivided the mean solar day into 24 equinoctial hours, each of which was subdivided sexagesimally, that is into the units of minute, second, third, fourth and fifth, creating the modern second as $\frac{1}{60}$ of $\frac{1}{60}$ of $\frac{1}{24}$ = $\frac{1}{86,400}$ of the mean solar day in the process.[7] With this definition, the second was proposed in 1874 as the base unit of time in the CGS system of units.[8] Soon afterwards Simon Newcomb and others discovered that Earth's rotation period varied irregularly,[9] so in 1952, the International Astronomical Union (IAU) defined the second as a fraction of the sidereal year. Because the tropical year was considered more fundamental than the sidereal year, in 1955, the IAU redefined the second as the fraction $\frac{1}{31,556,925.975}$ of the 1900.0 mean tropical year. In 1956, a slightly more precise value of $\frac{1}{31,556,925.9747}$ was adopted for the definition of the second by the International Committee for Weights and Measures, and in 1960 by the General Conference on Weights and Measures, becoming a part of the International System of Units (SI).[10]

Eventually, this definition too was found to be inadequate for precise time measurements, so in 1967, the SI second was again redefined as 9,192,631,770 periods of the radiation emitted by a caesium-133 atom in the transition between the two hyperfine levels of its ground state.[11] That value agreed to 1 part in 10^{10} with the astronomical (ephemeris) second then in use.[12] It was also close to $\frac{1}{86,400}$ of the mean solar day as averaged between years 1750 and 1892.

However, for the past several centuries, the length of the mean solar day has been increasing by about 1.4–1.7 ms per century, depending on the averaging time.[13][14][15] By 1961, the mean solar day was already a millisecond or two longer than 86,400 SI seconds.[16] Therefore, time standards that change the date after precisely 86,400 SI seconds, such as the International Atomic Time (TAI), will get increasingly ahead of time standards tied to the mean solar day, such as Greenwich Mean Time (GMT).



Graph showing the difference between UT1 and UTC. Vertical segments correspond to leap seconds.

When the Coordinated Universal Time standard was instituted in 1961, based on atomic clocks, it was felt necessary to maintain agreement with the GMT time of day, which, until then, had been the reference for broadcast time services. Thus, from 1961 to 1971, the rate of (some) atomic clocks was constantly slowed to remain synchronised with GMT. During that period, therefore, the "seconds" of broadcast services were actually slightly longer than the SI second and closer to the GMT seconds.

In 1972, the leap-second system was introduced so that the broadcast UTC seconds could be made exactly equal to the standard SI second, while still maintaining the UTC time of day and changes of UTC date synchronized with those of UT1 (the solar time standard that superseded GMT).[11] By then, the UTC clock was already 10 seconds behind TAI, which had been synchronized with UT1 in 1958, but had been counting true SI seconds since then. After 1972, both clocks have been ticking in SI seconds, so the difference between their readouts at any time is 10 seconds plus the total number of leap seconds that have been applied to UTC (37 seconds as of January 2017).

Insertion of leap seconds

The scheduling of leap seconds was initially delegated to the Bureau International de l'Heure (BIH), but passed to the International Earth Rotation and Reference Systems Service (IERS) on January 1, 1988. IERS usually decides to apply a leap second whenever the difference between UTC and UT1 approaches 0.6 s, in order to keep the difference between UTC and UT1 from exceeding 0.9 s.

The UTC standard allows leap seconds to be applied at the end of any UTC month, with first preference to June and December and second preference to March and September. As of January 2017, all of them have been inserted at the end of either June 30 or December 31. IERS publishes announcements every six months, whether leap seconds are to occur or not, in its "Bulletin C" (ftp://hpiers.obspm.fr/iers/bul/bulc/bulletinc.dat). Such announcements are typically published well in advance of each possible leap second date – usually in early January for June 30 and in early July for December 31.[17][18] Some time signal broadcasts give voice announcements of an impending leap second.

Between 1972 and 2018, a leap second has been inserted about every 20 months, on average. However, the spacing is quite irregular and apparently increasing: there were no leap seconds in the seven-year interval between January 1, 1999 and December 31, 2005, but there were nine leap seconds in the eight years 1972–1979.

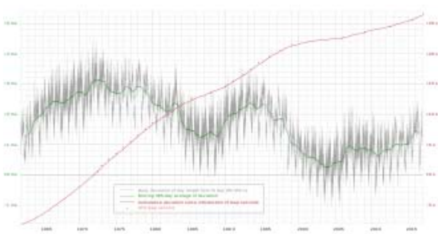
Unlike leap days, UTC leap seconds occur simultaneously worldwide; for example, the leap second on December 31, 2005 23:59:60 UTC was December 31, 2005 18:59:60 (6:59:60 p.m.) in U.S. Eastern Standard Time and January 1, 2006 08:59:60 (a.m.) in Japan Standard Time.

Not all clocks implement leap seconds in the same manner as UTC. Leap seconds in Unix time are commonly implemented by repeating the last second of the day. Network Time Protocol freezes time during the leap second. Other experimental schemes smear time in the vicinity of a leap second.[19]

Announced leap seconds to date

Year	Jun 30	Dec 31
1972	+1	+1
1973	0	+1
1974	0	+1
1975	0	+1
1976	0	+1
1977	0	+1
1978	0	+1
1979	0	+1
1980	0	0
1981	+1	0
1982	+1	0
1983	+1	0
1984	0	0
1985	+1	0
1986	0	0
1987	0	+1
1988	0	0
1989	0	+1
1990	0	+1
1991	0	0
1992	+1	0
1993	+1	0
1994	+1	0

Slowing rotation of the Earth



Deviation of day length from SI based day

Leap seconds are irregularly spaced because the Earth's rotation speed changes irregularly. Indeed, the Earth's rotation is quite unpredictable in the long term, which explains why leap seconds are announced only six months in advance.

A mathematical model of the variations in the length of the solar day was developed by F. R. Stephenson and L. V. Morrison,[15] based on records of eclipses for the period 700 BC to 1623 AD, telescopic observations of occultations for the period 1623 until 1967 and atomic clocks thereafter. The model shows a steady increase of the mean solar day by 1.70 ms (± 0.05 ms) per century, plus a periodic shift of about 4 ms amplitude and period of about 1,500 yr.[15] Over the last few centuries, the periodic component reduced the rate of lengthening of the mean solar day to about 1.4 ms per century.[20]

The main reason for the slowing down of the Earth's rotation is tidal friction, which alone would lengthen the day by 2.3 ms/century.[15] Other contributing factors are the movement of the Earth's crust relative to its core, changes in mantle convection, and any other events or processes that cause a significant redistribution of mass. These processes change the Earth's moment of inertia, affecting the rate of rotation due to conservation of angular momentum. Some of these redistributions increase earth's rotational speed, shorten the solar day and oppose tidal friction. For example, glacial rebound shortens the solar day by 0.6 ms/century and the 2004 Indian Ocean earthquake is thought to have shortened it by 2.68 microseconds.[21] It is evident from the figure that the Earth's rotation has slowed at a decreasing rate since the initiation of the current system in 1971, and the rate of leap second insertions has therefore been decreasing.

Proposal to abolish leap seconds

The utility of leap seconds is disputed. The main motivation of leaps in UTC is historical: to keep Greenwich as the reference not only for longitude (Greenwich meridian) but also for civil time (Greenwich Mean Time). However, even at Greenwich, leap seconds do not ensure that the sun culminates exactly at 12:00.00,000 UTC, as noon deviates from it up to 6 minutes over the year. All Sundials show an offset to civil time. Professional astronomers do not rely on UTC, but on UT1, which has no leap seconds but a varying offset to UTC expressed in DUT1. Orienting a space telescope such as the Hubble Space Telescope cannot use leap seconds. GPS navigation uses the linear GPS time scale, as a one-second leap would cause a location error of up to 460m (1/4 nautical mile). Citizens accept yearly variations of one hour because of Daylight saving time, they do not care about second-accurate noon. If the difference between solar time at a particular location and local time would matter, users simply could add the difference of UTC to UT1, DUT1 (which is broadcast), similarly as they do today for the difference between geographical North and magnetic North. If the difference between solar noon and local time 12:00 would exceed half an hour (that without leap seconds would occur in some 1000 years from now), a country could change its time zone to align it with its mean solar day, leap seconds are not needed.

The irregularity and unpredictability of UTC leap seconds is problematic for several areas, especially computing. For example, to compute the elapsed time in seconds between two given UTC past dates requires the consultation of a table of leap seconds, which needs to be updated whenever a new leap second is announced. Moreover, it is not possible to compute accurate time intervals for UTC dates that are more than about six months in the future. Most time distribution systems (SNTP, IRIG-B, PTP) only announce leap seconds at most 12 hours in advance and sometimes only in the last minute. With increasing requirements for accuracy in automation systems and high-speed trading, this raises a number of issues, as a leap second represents a jump often a million times larger than the required accuracy.

On July 5, 2005, the Head of the Earth Orientation Center of the IERS sent a notice to IERS Bulletins C and D subscribers, soliciting comments on a U.S. proposal before the ITU-R Study Group 7's WP7-A to eliminate leap seconds from the UTC broadcast standard before 2008 (the ITU-R is responsible for the definition of UTC).[a] It was expected to be considered in November 2005, but the discussion has since been postponed.[23] Under the proposal, leap seconds would be technically replaced by leap hours as an attempt to satisfy the legal requirements of several ITU-R member nations that civil time be astronomically tied to the Sun.

A number of objections to the proposal have been raised. Dr. P. Kenneth Seidelmann, editor of the Explanatory Supplement to the Astronomical Almanac, wrote a letter lamenting the lack of consistent public information about the proposal and adequate justification.[24] Steve Allen of the University of California, Santa Cruz cited what he claimed to be the large impact on astronomers in a *Science News* article.[25] He has an extensive online site[26] devoted to the issues and the history of leap seconds, including a set of references about the proposal and arguments against it.[27]

At the 2014 General Assembly of the International Union of Radio Scientists (URSI), Dr. Demetrios Matsakis, the United States Naval Observatory's Chief Scientist for Time Services, presented the reasoning in favor of the redefinition and rebuttals to the arguments made against it.[28] He stressed the practical inability of software programmers to allow for the fact that leap seconds

1995	0	+1
1996	0	0
1997	+1	0
1998	0	+1
1999	0	0
2000	0	0
2001	0	0
2002	0	0
2003	0	0
2004	0	0
2005	0	+1
2006	0	0
2007	0	0
2008	0	+1
2009	0	0
2010	0	0
2011	0	0
2012	+1	0
2013	0	0
2014	0	0
2015	+1	0
2016	0	+1
2017	0	0
2018	0	0
Year	**Jun 30**	**Dec 31**
Total	11	16

	27
Current TAI − UTC	
37	

make time appear to go backwards, particularly when most of them do not even know that leap seconds exist. The possibility of leap seconds being a hazard to navigation was presented, as well as the observed effects on commerce.

The United States formulated its position on this matter based upon the advice of the National Telecommunications and Information Administration[29] and the Federal Communications Commission (FCC), which solicited comments from the general public.[30] This position is in favor of the redefinition.[31][b]

In 2011, Chunhao Han of the Beijing Global Information Center of Application and Exploration said China had not decided what its vote would be in January 2012, but some Chinese scholars consider it important to maintain a link between civil and astronomical time due to Chinese tradition. The 2012 vote was ultimately deferred.[33] At an ITU/BIPM-sponsored workshop on the leap second, Dr. Han expressed his personal view in favor of abolishing the leap second,[34] and similar support for the redefinition was again expressed by Dr. Han, along with other Chinese timekeeping scientists, at the URSI General Assembly in 2014.

At a special session of the Asia-Pacific Telecommunity Meeting on February 10, 2015, Chunhao Han indicated China was now supporting the elimination of future leap seconds, as were all the other presenting national representatives (from Australia, Japan, and the Republic of Korea). At this meeting, Bruce Warrington (NMI, Australia) and Tsukasa Iwama (NICT, Japan) indicated particular concern for the financial markets due to the leap second occurring in the middle of a workday in their part of the world.[c] Subsequent to the CPM15-2 meeting in March/April 2015 the draft gives four methods which the WRC-15 might use to satisfy Resolution 653 from WRC-12.[37]

Arguments against the proposal include the unknown expense of such a major change and the fact that universal time will no longer correspond to mean solar time. It is also answered that two timescales that do not follow leap seconds are already available, International Atomic Time (TAI) and Global Positioning System (GPS) time. Computers, for example, could use these and convert to UTC or local civil time as necessary for output. Inexpensive GPS timing receivers are readily available, and the satellite broadcasts include the necessary information to convert GPS time to UTC. It is also easy to convert GPS time to TAI, as TAI is always exactly 19 seconds ahead of GPS time. Examples of systems based on GPS time include the CDMA digital cellular systems IS-95 and CDMA2000. In general, computer systems use UTC and synchronize their clocks using Network Time Protocol (NTP). Systems that cannot tolerate disruptions caused by leap seconds can base their time on TAI and use Precision Time Protocol. However, the BIPM has pointed out that this proliferation of timescales leads to confusion.[38]

At the 47th meeting of the Civil Global Positioning System Service Interface Committee in Fort Worth, Texas in September 2007, it was announced that a mailed vote would go out on stopping leap seconds. The plan for the vote was:[39]

- April 2008: ITU Working Party 7A will submit to ITU Study Group 7 project recommendation on stopping leap seconds
- During 2008, Study Group 7 will conduct a vote through mail among member states
- October 2011: The ITU-R released its status paper, *Status of Coordinated Universal Time (UTC) study in ITU-R*, in preparation for the January 2012 meeting in Geneva; the paper reported that, to date, in response to the UN agency's 2010 and 2011 web based surveys requesting input on the topic, it had received 16 responses from the 192 Member States with "13 being in favor of change, 3 being contrary."[40]
- January 2012: The ITU makes a decision.

In January 2012, rather than decide yes or no per this plan, the ITU decided to postpone a decision on leap seconds to the World Radiocommunication Conference in November 2015. At this conference, it was again decided to continue using leap seconds, pending further study and consideration at the next conference in 2023.[41]

In October 2014, Dr. Włodzimierz Lewandowski, chair of the timing subcommittee of the Civil GPS Interface Service Committee and a member of the ESA Navigation Program Board, presented a CGSIC-endorsed resolution to the ITU that supported the redefinition and described leap seconds as a "hazard to navigation".[42]

Some of the objections to the proposed change have been answered by its opponents. For example, Dr. Felicitas Arias, who, as Director of the International Bureau of Weights and Measures (BIPM)'s Time, Frequency, and Gravimetry Department, is responsible for generating UTC, noted in a press release that the drift of about one minute every 60–90 years could be compared to the 16-minute annual variation between true solar time and mean solar time, the one hour offset by use of daylight time, and the several-hours offset in certain geographically extra-large time zones.[43]

Examples of problems associated with the leap second

While the textual representation of leap seconds is defined by BIMP as "23:59:60", computers derive this human-readable representation from a binary counter giving the number of seconds elapsed since an Epoch (reference date), for instance since 1970-01-01 00:00:00 in Unix machines. This counter has no indicator that a leap second is occurring. Some computers, in particular Linux, assign to the leap second the number of the preceding 23:59:59 second (9-9-0 sequence), while other computers assign to the leap second the counter value of the next 00:00:00 second (9-0-0 sequence). The BIMP definition in Bulletin C52 [1] calls for the 9-0-0 sequence. Since there is no standard governing the sequence, the time stamp values can vary by one second. Entering "2016-12-31 23:59:60 in a POSIX converter will fail and XML will reject such date as "invalid time". This may explain many flaws in time-critical systems that occur when exchanging time-stamped values.

A number of organizations reported problems caused by flawed software following the June 30, 2012 leap second. Among the sites which reported problems were Reddit (Apache Cassandra), Mozilla (Hadoop),[44] Qantas,[45] and various sites running Linux.[46]

Older versions of Motorola Oncore VP, UT, GT, and M12 GPS receivers had a software bug that would cause a single timestamp to be off by a day if no leap second was scheduled for 256 weeks. On November 28, 2003, this happened. At midnight, the receivers with this firmware reported November 29, 2003 for one second and then reverted to November 28, 2003.[47][48]

Older Trimble GPS receivers had a software flaw that would insert a leap second immediately after the GPS constellation started broadcasting the next leap second insertion time (some months in advance of the actual leap second), rather than waiting for the next leap second to happen. This left the receiver's time off by a second in the interim.[49][50]

Older Datum Tymeserve 2100 GPS receivers and Symmetricom Tymeserve 2100 receivers also have a similar flaw to that of the older Trimble GPS receivers, with the time being off by one second. The advance announcement of the leap second is applied as soon as the message is received, instead of waiting for the correct date. A workaround has been described and tested, but if the GPS system rebroadcasts the announcement, or the unit is powered off, the problem will occur again.[51]

On January 21, 2015, several models of GPS receivers implemented the leap second as soon as the announcement was broadcast by GPS, instead of waiting until the implementation date of June 30.[52]

The NTP packet includes a leap second flag, which informs the user that a leap second is imminent. This, among other things, allows the user to distinguish between a bad measurement that should be ignored and a genuine leap second that should be followed. It has been reported that never, since the monitoring began in 2008 and whether or not a leap second should be inserted, have all NTP servers correctly set their flags on a December 31 or June 30.[53][54] This is one reason many NTP servers broadcast the wrong time for up to a day after a leap second insertion,[55] and it has been suggested that hackers have exploited this vulnerability.[56][57]

Four different brands of marketed navigational receivers that use data from GPS or Galileo along with the Chinese BeiDou satellites, and even some receivers that use BeiDou satellites alone, were found to implement leap seconds one day early.[58] This was traced to the fact that BeiDou numbers the days of the week from 0 to 6, while GPS and Galileo number them from 1 to 7. The problem was found to exist in commercial simulators that are used by manufacturers to test their equipment.

The effect of leap seconds on the commercial sector has been described as "a nightmare".[59] Because financial markets are vulnerable to both technical and legal leap second problems, the Intercontinental Exchange, parent body to 7 clearing houses and 11 stock exchanges including the New York Stock Exchange, ceased operations for 61 minutes at the time of the June 30, 2015 leap second.[60]

Despite the publicity given to the 2015 leap second, Internet network failures occurred due to the vulnerability of at least one class of router.[61] Also, interruptions of around 40 minutes duration occurred with Twitter, Instagram, Pinterest, Netflix, Amazon, and Apple's music streaming series Beats 1.[62]

Several versions of the Cisco Systems NEXUS 5000 Series Operating System NX-OS (versions 5.0, 5.1, 5.2) are affected.[63]

The 2015 leap second also affected the Altea airlines reservation system used by Qantas and Virgin Australia.[64]

Cloudflare was affected by the 2016 leap second. Its DNS resolver implementation calculated a negative number when subtracting two timestamps obtained from the Go programming language's `time.Now()` function, which then used only a real-time clock source.[65] This could have been avoided by using a monotonic clock source, which has since been added to Go 1.9.[66]

There were concerns that farming equipment using GPS during harvests occurring on December 31, 2016 would be affected by the 2016 leap second.[67]

Workarounds for leap second problems

The most obvious workaround is to use the TAI scale for all operational purposes and convert to UTC for human-readable text. UTC can always be derived from

TAI with a suitable table of leap seconds. The video/audio industry standard SMPTE moved to TAI for time stamping frames [68]. IEC/IEEE 60802 (Time sensitive networks) specifies TAI for all operations. Grid automation is planning to switch to TAI for global distribution of events in electrical grids.

Instead of inserting a leap second at the end of the day, Google servers implement a *leap smear*, extending seconds slightly over a time window prior to the leap second.[69] Amazon followed a similar, but slightly different, pattern for the introduction of the June 30, 2015 leap second,[70] leading to another case of the proliferation of timescales. They later released an NTP service for EC2 instances which performs leap smearing.[71]

It has been proposed that media clients using the Real-time Transport Protocol inhibit generation or use of NTP timestamps during the leap second and the second preceding it.[72]

NIST has established a special NTP time server to deliver UT1 instead of UTC.[73] Such a server would be particularly useful in the event the ITU resolution passes and leap seconds are no longer inserted.[74] Those astronomical observatories and other users that require UT1 could run off UT1 – although in many cases these users already download UT1-UTC from the IERS, and apply corrections in software.[75]

See also

- Clock drift, phenomenon where a clock gains or loses time compared to another clock
- Delta-T (ΔT), the time difference obtained by subtracting Universal Time from Terrestrial Time
- Dynamical time scale
- Leap year, a year containing one extra day or month

Notes

a. *The Wall Street Journal* noted that the proposal was considered by a U.S. official at the time to be a "private matter internal to the ITU."[22]

b. The FCC has posted its received comments, which can be found using their search engine for proceeding 04-286 and limiting the "received period" to those between January 27 and February 18, 2014 inclusive.[32]

c. In addition to publishing the video of the special session,[35] the Australian Communications and Media Authority has a transcript of that session and a web page with draft content of the Conference Preparatory Meeting report and solutions for ITU-R WRC-15 Agenda Item 1.14.[36]

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External links

- LeapSecond.com - A web site dedicated to precise time and frequency (http://www.leapsecond.com/)
- NIST FAQ about leap year and leap second (https://www.nist.gov/pml/div688/leapseconds.cfm)
- The leap second: its history and possible future (http://www.cl.cam.ac.uk/~mgk25/time/metrologia-leapsecond.pdf)
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- Microsoft announces support for leap seconds in Microsoft Windows (https://blogs.technet.microsoft.com/networking/2018/07/18/top10-ws2019-hatime/)