Annex C

(informative)

Timescales and epochs

C.1 Overview

A more detailed discussion of many of the topics in this annex can be found in Allan et al. [B3].

For historical reasons, time is specified in a variety of ways as listed in Table C-1. GPS, PTP, and TAI times are based on values yielded by atomic clocks and advance on each second. NTP and UTC times are similar, but are occasionally adjusted by one leap second, to account for differences between the atomic clocks and the rotation time of the earth.

Table C-1—Timescale parameters

	Timescale				
Parameter	**GPS**	**PTP**	**TAI**	**NTP**	**UTC**
Approximate epoch[a]	1980-01-06 1999-08-22 2019-04-07	1970-01-01	No epoch defined	1900-01-01	No epoch defined
Representation	weeks.seconds	seconds	YYYY-MM-DD hh:mm:ss	seconds	YYYY-MM-DD hh:mm:ss
Rollover (years)	19.7	≈8 900 000	10 000	≈136	10 000
NOTE 1—After 1972-01-01 00:00:00 TAI, TAI and UTC differ by only integer seconds. NOTE 2—The following represent the same instant in time: 1958-01-01 00:00:00 TAI and 1958-01-01 00:00:00 UTC					

[a] Each approximate epoch occurs at 00:00:00 on the respective date.

GPS global positioning satellite
NTP network time protocol
PTP IEEE 1588 precision time protocol
TAI International Atomic Time (from the French term *Temps Atomique International*)
UTC Coordinated Universal Time [The abbreviation is a compromise between the English phrase *coordinated universal time* (CUT) and the French phrase *temps universel coordonné* (TUC).]

C.2 TAI and UTC

TAI and UTC are international standards for time based on the SI second (see Allan et al. [B3], IAU [B27], and Petit and Luzum [B26]). The SI second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.[18] TAI is implemented by a suite of atomic clocks and forms the timekeeping basis for other timescales in common use. The rate at which UTC time advances is normally identical to the rate of

[18] See ITU-R TF.460-6 [B20], Jekeli [B22], Service de la Rotation Terrestre [B28], SI [B14], IAU [B27], and Petit and Luzum [B26] for more details on UTC, TAI, and the SI second.

TAI. An exception is an occasion when UTC is modified by adding or subtracting exactly one whole leap second. The TAI frequency is the frequency of a signal whose period is the TAI second.

The TAI and UTC timescales were introduced as of 1958-01-01, and the times 1958-01-01 00:00:00 TAI and 1958-01-01 00:00:00 UTC represent the same instant in time. However, this instant in time is not an epoch for TAI and UTC. An epoch, in the sense of the origin of a timescale (see 8.2.2), is not defined for either TAI or UTC. TAI and UTC are expressed in the form YYYY-MM-DD hh:mm:ss, rather than as elapsed time since an epoch; here, YYYY-MM-DD denotes the date, and hh:mm:ss denotes the time in each day.

Prior to 1972-01-01, corrections to the offset between UTC and TAI were made by applying fractional-second corrections to UTC and corrections to the rate at which UTC advanced relative to the rate at which TAI advanced. After 1972-01-01, leap-second corrections are applied to UTC by inserting or deleting second(s) at the end of the last minute of preferably the last day of June or December. Also after 1972-01-01, UTC and TAI advance at the same rate. As of 2006-01-01, TAI and UTC times differed by +33 s (i.e., TAI time minus UTC time equals +33 s for 2006-01-01).

In computer networks, the common POSIX-based time conversion algorithms are typically used to produce the correct ISO 8601:2004 [B15] printed representations for both TAI and UTC.

The PTP epoch is set such that a direct application of the POSIX algorithm to a PTP timescale timestamp converts the PTP timestamp to the ISO 8601:2004 [B15] printed representation of TAI. PTP also distributes the current offset between TAI and UTC in the currentUtcOffset field of Announce messages. Except during leap seconds, subtracting currentUtcOffset from a PTP timestamp and then applying the POSIX algorithm result in the ISO 8601:2004 printed representation of UTC. Conversely, except during leap seconds, applying the inverse POSIX algorithm and adding currentUtcOffset convert from the ISO 8601:2004 printed form of UTC to the form required to generate a PTP timestamp.

For example, at 0h 2 January 1972 TAI, the value of PTP Instance Time was 63 158 400. At this time currentUtcOffset was 10. The POSIX algorithm applied to the value (63 158 400 – 10) gives a value of 1972-01-01 23:59:50 (10 s before 0h 2 January 1972 UTC). The value of PTP Instance Time on 0h 2 January 1972 TAI is computed by observing that PTP Instance Time = 0 on 0h 1 January 1970 TAI, i.e., Modified Julian Day (MJD) 40587 (see Petit and Luzum [B26]). On 0h 2 January 1972 TAI, MJD = 41 318. Thus, PTP Instance Time on 0h 2 January 1972 TAI is 0 + 86 400 × (41 318 – 40 587). Note that if this calculation were done for a day in which a leap second occurred, a more complex algorithm would be required to ensure that, for the duration of the leap second, the ISO 8601:2004 [B15] print form seconds value was 60 for a positive leap second.

International standards specify that if a correction to UTC relative to TAI is required, the leap second occurs at the last second of the UTC day, preferably at the end of June 30 or December 31. For a negative leap second, the last minute of the designated day has only 59 seconds. Negative leap seconds have never occurred and are unlikely to occur in the future. For a positive leap second, the last minute of the designated day has 61 seconds.

Although a negative leap second is unlikely to occur, if such a correction becomes necessary, the ISO 8601:2004 [B15] printed representation would appear as follows for a hypothetical negative leap second on 30 June 1972 UTC:

1972-06-30 23:59:57, 1972-06-30 23:59:58, 1972-07-01 00:00:00

For the positive leap second that actually occurred on 30 June 1972 UTC, the ISO 8601:2004 [B15] printed representation appeared as follows:

1972-06-30 23:59:59, 1972-06-30 23:59:60, 1972-07-01 00:00:00

Note the 23:59:60 notation to indicate the added second.

The update semantics for leap second updates in PTP are discussed in B.2.2 of IEEE Std 1588-2019.

C.3 NTP and GPS

Two standard time sources of particular interest in implementing PTP Instances: NTP and GPS. Both NTP and GPS systems are expected to provide time references for calibration of the grandmaster-supplied PTP time.

NTP represents seconds as a 32-bit unsigned integer that rolls-over every 2^{32} s ≈ 136 year, with the first such rollover occurring in the year 2036. The precision of NTP systems is usually in the millisecond range.

NTP is a widely used protocol for synchronizing computer systems. NTP is based on sets of servers, to which NTP clients synchronize. These servers themselves are synchronized to time servers that are traceable to international standards.

NTP version 4 provides the current UTC time and warning flags indicating that a leap second will be inserted at the end of the current UTC day. The NTP clock effectively stops for one second when the leap second is inserted.

GPS time comes from a global positioning satellite system, GPS, maintained by the U.S. Department of Defense. The precision of GPS system is usually in the 10 ns to 100 ns range. GPS system transmissions represent the time as {*weeks*, *secondsInWeek*}, the number of weeks since the GPS epoch and the number of seconds since the beginning of the current week.

GPS provides a leap seconds offset and warning flags marking the introduction of a leap second correction (see IS-GPS-200J [B19]). UTC and TAI times can be computed solely based the information contained in the GPS transmissions.

GPS timing receivers generally manage the epoch transitions (1024-week rollovers), providing the correct time (YYYY-MM-DD hh:mm:ss) in TAI and/or UTC timescales, and often also local time; in addition to providing the raw GPS week, second of week, and leap-second information.

C.4 Timescale conversions

Previously discussed representations of time can be readily converted to/from PTP *time* based on a constant offset and the distributed *utcOffset* value, as specified in Table C-2. Within Table C-2, all variables represent integers; "/" and "%" represent a integer divide and remainder operation, respectively.

NOTE—Some of the conversions in Table C-2 will not give the correct result when the current second is a leap second.

Table C-2—Timescale conversions

ta		PTP value tb
Name	**Format**	
GPS	weeks:seconds	tb = ta.seconds + 315 964 819 + (gpsRollovers * 1024 + ta.weeks) * (7 * DAYSECS);
		ta.weeks = (tb – 315 964 819) / (7 * DAYSECS) – gpsRollovers*1024; ta.seconds = (tb – 315 964 819) % (7 * DAYSECS);
TAI	date{YYYY,MM,DD}:time{hh,mm,ss}	tb = DateToDays("1970-01-01", ta.date) * DAYSECS + ((ta.time.hh * 24) + ta.time.mm) *60) + ta.time.ss;

		secs = tb % DAYSECS;
		ta.date = DaysToDate("1970-01-01", tb / DAYSECS);
		ta.time.hh = secs / 3600;
		ta.time.mm = (secs % 3600)/60;
		ta.time.ss = (secs % 60);

NTP	seconds	tb = (ta+utcOffset)–2208988800;
		ta = (tb–utcOffset)+2208988800;
UTC	date{YYYY,MM,DD}:time{hh,mm,ss}	tb = DateToDays("1970-01-01", ta.date) * DAYSECS + ((ta.time.hh * 24) + ta.time.mm) *60) + ta.time.ss + utcOffset;

		tc = tb – utcOffset;
		secs = tc % DAYSECS;
		ta.date = DaysToDate("1970-01-01", tc/DAYSECS);
		ta.time.hh = secs / 3600;
		ta.time.mm = (secs % 3600)/60;
		ta.time.ss = (secs % 60);

gpsRollovers Currently equals 1; changed from 0 to 1 between 1999-08-15 and 1999-08-22
DAYSECS The number of seconds within a day: (60 × 60 × 24)
utcOffset The difference TAI – UTC, in seconds [i.e., currentUtcOffset (see 8.2.3)]
DateToDays For arguments DateToDays(*past*, *present*), returns days between *past* and *present* dates
DaysToDate For arguments DaysToDate(*past*, *days*), returns the current date, *days* after the *past* date

C.5 Time zones and GMT

The term *Greenwich Mean Time* (GMT) once referred to mean solar time at the Royal Observatory in Greenwich, England. GMT now commonly refers to the timescale UTC; or the UK winter time zone (Western European Time, WET). Such GMT references are, strictly speaking, incorrect but nevertheless quite common. The following representations correspond to the same instant of time:

18:07:00 (GMT), commonplace usage	13:07:00 (Eastern Standard Time, EST)
18:07:00 (UTC)	01:07 PM (Eastern Standard Time, EST)
18:07:00 (Western European Time, WET)	10:07:00 (Pacific Standard Time, PST)
06:07 PM (Western European Time, WET)	10:07 AM (Pacific Standard Time, PST)