ITUNews
MAGAZINE

No. 2
2023

The future of Coordinated Universal Time

Stay current // // Stay informed

Discover ITU News

Your gateway to digital news and insights

blog

magazine

newsletter

Time in today's world

Doreen Bogdan-Martin, ITU Secretary-General

> *Timekeeping enables us to be synchronized and organized.*
>
> Doreen Bogdan-Martin

Time is crucial to our lives on Earth. Our societies have long depended on it.

Time is probably one of the most important commodities we have. Without timekeeping, there would be no delimitation of specific days or months, birthdays or anniversaries, precise noons or midnights. Even if we rarely reflect on why time matters, we would simply be lost without it. Timekeeping enables us to be synchronized and organized.

A complex web of timekeeping systems enables us to manage time in our day-to-day existence in a world that is constantly evolving. Time is displayed everywhere – on computers, smartphones, TVs, and all other kinds of applications and systems. Different entities, from tech companies and satellite navigation systems to broadcasters and astronomers, all depend on reliable timekeeping.

In recent years, some experts have sought to amend Coordinated Universal Time (UTC), calling into question the need for "leap second" adjustments. In today's digital world, the quest for precise and widely accepted timekeeping prompts questions about how, and whether, to reconcile the unevenness of Earth's rotation with the steady pulse of atomic time.

The perspectives of the authors of this *ITU News Magazine* edition are sure to inform the ongoing debate on this topic ahead of the World Radiocommunication Conference (WRC-23) in November and December.

Radiocommunication is key for the International Telecommunication Union (ITU) to drive sustainable digital transformation and achieve meaningful connectivity for everyone. Let us work together to ensure that future timekeeping works for all of humanity.

The future of Coordinated Universal Time

Cover photo: Adobe Stock (Image element from NASA)

ISSN 1020-4148
itunews.itu.int
Six issues per year

Editor-in-Chief: Neil MacDonald
Editorial Assistant: Angela Smith
Digital Communication Editor: Christine Vanoli

Editorial office:
Tel.: +41 22 730 5723/5683
E-mail: itunews@itu.int

Mailing address:
International Telecommunication Union
Place des Nations
CH–1211 Geneva 20 (Switzerland)

Adobe Stock

The future of timekeeping

Mario Maniewicz, Director,
ITU Radiocommunication Bureau

Regardless of how you measure it, time is critical to all our daily activities and the orderly functioning of our societies. Defining time has been and continues to be a preoccupation of scientists around the world. After years of using the rotation of the Earth as the basis for determining the length of a day and for defining time scales, the adoption of Coordinated Universal Time (UTC) in 1971 marked a breakthrough in the definition of time.

Just over half a century on, I am delighted to present to you this special *ITU News Magazine* edition on future use and applications of UTC. Prepared by the International Telecommunication Union (ITU) and the *Bureau international des poids et mesures* (BIPM – the International Bureau of Weights and Measures), it contains articles and discourse on the future of the various ways in which time is recorded.

ITU plays a central role in the definition and dissemination of UTC, mainly through the ITU Radiocommunication Sector (ITU-R) Working Party (WP) 7A, which is mandated to deal with scientific services related to time signals and standard frequency emissions.

"Regardless of how you measure it, time is critical to all our daily activities and the orderly functioning of our societies."

Mario Maniewicz

The scope of WP 7A includes the dissemination, reception and exchange of standard frequency and time signal services and their coordination on a worldwide basis. One of the fundamental products of WP 7A is Recommendation ITU-R TR.460-6, "Standard-frequency and time-signal emissions". Incorporated by reference in the ITU Radio Regulations, this provides the official definition of UTC.

A universal reference time scale

Currently, UTC is used for a range of different purposes, from the minutes needed by the public in adhering to timetables to the synchronized nanoseconds required in the most demanding applications, such as navigation through the global navigation satellite systems – for example, the Global Positioning System (GPS), GLONASS and more recently Europe's Galileo and China's BeiDou.

The need for a unique universal reference time scale has been raised by most user communities, international organizations, and timing experts. The primary challenge is to make UTC a continuous time scale, rather than the stepped atomic time scale that it is now. There is consensus that alternate time scales and system times should not be utilized as timing reference sources, and that the practices for realizing UTC should be adapted to the needs of users in the 21st Century.

The change would bring the benefit of a continuous time scale, available for the operation of all modern electronic navigation and computerized systems. It would eliminate the need for specialized ad hoc system times used to avoid UTC's unpredictable one-second steps.

What does the future look like?

To satisfy the largest number of applications possible, the future reference time scale should be:

- internationally realized,
- universally accepted, and
- continuous (at least for a long time).

It is also important that the future reference time scale has a known relation with the rotation of the Earth, as well as a widely known and disseminated offset from Universal Time (UT1). A future reference time scale could maintain the advantages of the legacy UTC while addressing these requirements. It could be obtained by keeping the current UTC, as defined by the General Conference on Weights and Measures 2022, while relaxing the limitation on the offset between UT1 and UTC.

"The need for a unique universal reference time scale has been raised by most user communities, international organizations, and timing experts."

A suitable transition period

Changes in any reference time scale raise questions about compatibility with past or previously set systems and devices. Considering its importance to many aspects of critical national infrastructures, clear measures are needed to address the backward compatibility issue if a decision on a future reference time scale is made.

To give legacy systems an adequate period to adapt to the change in UTC, some users – including astronomers, maritime navigation, maritime mobile, aeronautical and radiodetermination services, and fixed, mobile and broadcasting services – have asked for a transition period to update their systems. In the case of GLONASS, this would be no less than 15 years between the decision and implementation.

In any case, the transition period should be long enough to allow existing user equipment to continue operating without affecting the quality of service. Recommendation ITU-R TR.460-6 will be updated during the transition to a continuous time scale.

> *"The upcoming WRC-23 in Dubai, United Arab Emirates, will consider the results of ITU-R studies on the impact of changing time scales."*

ITUWRC DUBAI2023
20 November – 15 December 2023
Dubai, United Arab Emirates

ITU studies to be considered at WRC-23

The upcoming World Radiocommunication Conference (WRC-23) in Dubai, United Arab Emirates, will consider the results of ITU-R studies on the impact of changing time scales, responding to the earlier Resolution 655 (WRC-15). Further information on the topic is contained in Report ITU-R TR.2511-0, "Content and structure of time signals to be disseminated by radiocommunication systems and various aspects of current and potential future reference time scales, including their impacts and applications in radiocommunication".

> *"I am very grateful to BIPM and the authors of this edition of the ITU News Magazine for sharing their expertise and perspectives."*

Sharing expertise and perspectives

I am very grateful to BIPM and the authors of this edition of the *ITU News Magazine* for sharing their expertise and perspectives. Their combined knowledge offers a classic resource and reference on the science of timekeeping that will enrich and inform the ongoing debate on the future of time – and on whether to abolish the leap second.

The future starts now

Martin Milton, Director, BIPM

As humankind and human behaviour continue evolving, demands for an improved time scale have become more frequent and intense.

Martin Milton

Agreements on timekeeping have been essential to human progress for millennia. As humankind and human behaviour continue evolving, demands for an improved time scale have become more frequent and intense.

During 2021, the International Bureau of Weights and Measures (*Bureau international des poids et mesures* – BIPM), conducted a survey among its users and stakeholders about the impact of discontinuities in Coordinated Universal Time (UTC) on current applications of timekeeping. The data collected shows that only a truly continuous UTC – precisely measured and without frequent adjustments – can serve the needs of the 21st Century user.

Change is always with us. Nevertheless, as the institutional custodians of international time, we must proceed with care and consideration. As we move forward with this topic, we must respect the fact that tangible everyday astronomical cycles remain the symbolic foundation of time for practically everyone.

Because of that, we must consider the impact that any decision to change in UTC would have on astronomy, along with any social activities linking people to the natural cycle of the Earth.

A recent decision on future UTC

The General Conference on Weights and Measures (CGPM) in November 2022 brought together 64 BIPM member states. They approved a resolution "On the use and future development of UTC," proposing that an extension of the tolerance between UTC and the rotational angle of the Earth be put in place by 2035.

In view of this decision, BIPM looks forward to collaborating with industries and organizations, and, of course, with the International Telecommunication Union (ITU), on realizing and disseminating an updated time standard adapted to the needs of a modern society.

"A continuous UTC might one day become the time reference for the Earth and beyond."

A turning point

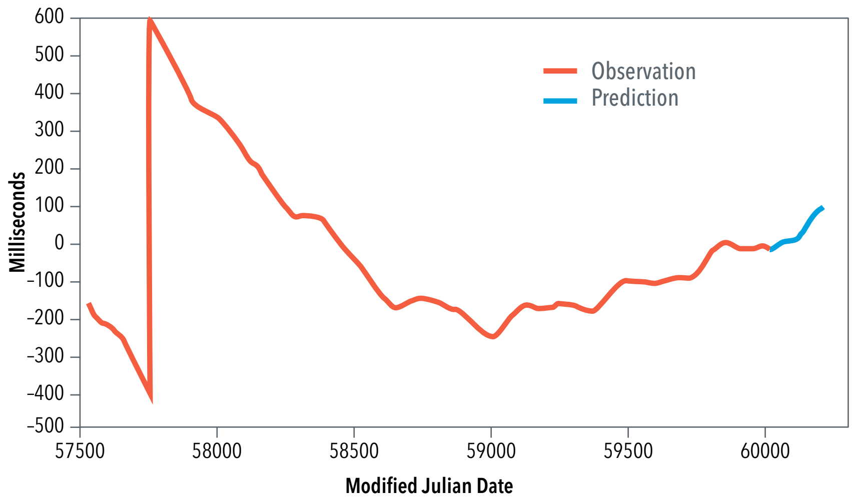
As the graph below shows, we are indeed at a turning point in the history of UTC.

The difference between the Earth's rotation time and atomic time has widened considerably over the last 50 years. This trend, exacerbated by the slowing down of the Earth's rotation, has triggered the insertion of occasional leap seconds.

The latest data, however, indicate a reverse in the trend, giving rise to the possibility that between now and 2035 we may need to insert the first-ever negative leap second into UTC-based time applications.

As I write this article, space agencies around the world are starting to discuss the need for a continuous time reference for the moon. A continuous UTC, therefore, might one day become the time reference for the Earth and beyond.

UT1 – UTC



Source: EOC

Is the leap second history?

Similar questions about global timekeeping came up a decade ago, in an *ITU News Magazine* edition published in 2013. As the foreword from François Rancy, then-Director of the ITU Radiocommunications Bureau, said: "Modern times – is the leap second history?"

Now, 10 years later, it could well be the case.

ITU News Magazine edition published in 2013: The future of time

Download your copy

Adobe Stock

Progress on time signals and frequency standard emissions

Joseph Achkar, Chairman, ITU Radiocommunication Sector Working Party 7A

"The future reference time scale needs to be internationally realized, universally accepted, and continuous."

Joseph Achkar

Working Party 7A in the ITU Radiocommunication Sector (ITU-R – one of three sectors of the International Telecommunication Union) deals with scientific services related to time signals and frequency standard emissions.

In 2015, the World Radiocommunication Conference adopted Resolution 655 (WRC-15), "Definition of time scale and dissemination of time signals via radiocommunication systems," following 15 years of discussions within Working Party 7A. The issue was first raised because the occasional insertion of leap seconds into Coordinated Universal Time (UTC) had started creating serious operational difficulties for many navigation, industrial, financial, and telecommunication systems.

Recommendation ITU-R TF.460, initiated in 1970 by the International Radio Consultative Committee (CCIR), originally raised the need to disseminate standard frequencies and time signals in conformity with the second, as defined in 1967 by the General Conference of Weights and Measures (*Conférence générale des poids et mesures* – CGPM).

This recommendation states that all standard-frequency and time-signal emissions should conform as closely as possible to UTC. It also describes the procedure for the occasional insertion of leap seconds into UTC.

Timekeeping and dissemination guidance

Since 2016, Working Party 7A has intensified studies on this issue in close collaboration with other relevant organizations, as well as with ITU's Telecommunication Standardization Sector (ITU-T), the results of which are in ITU-R Report TF.2511.

The report, responding to Resolution 655, is intended to inform ITU Member State administrations and Sector Members – as well as telecommunication companies, Internet providers, space agencies, aviation, maritime and meteorological organizations, universities, and authorities beyond ITU's membership – of the regulatory, technical and practical aspects of timekeeping and dissemination of standard frequency and time signals.

The future reference time scale needs to be internationally realized, universally accepted, and continuous. This could be obtained by maintaining UTC and by relaxing the limitation on the offset between UTC and UT1, meaning Universal Time based on Earth's rotation.

As Working Party 7A's studies indicate, the determination of how the international reference time scale relates to other time sources, including UT1, falls under the authority of the International Bureau of Weights and Measures (*Bureau international des poids et mesures* – BIPM) in conjunction with the Consultative Committee for Time and Frequency (CCTF), the International Committee for Weights and Measures (*Comité international des poids et mesures* – CIPM) and CGPM. However, standard-frequency and time-signal emissions and dissemination, including for time scale offsets, reside within the authority of ITU-R.

While some user groups would like to see leap seconds come to an end as soon as possible, others hope to update their systems and procedures first, prompting them to request a 15-year transition period between decision and implementation.

ITU study report

Topics covered in Report TF.2511 include:

- Background of UTC.
- Importance of UTC.
- Role of organizations.
- Impact of leap seconds.
- Current and future time scales.
- Dissemination of time signals.

Download the Report.

"While some user groups would like to see leap seconds come to an end as soon as possible, others hope to update their systems and procedures first."

Preparing for WRC-23

The Director of the ITU Radiocommunication Bureau will report the conclusions of Working Party 7A's studies to the upcoming World Radiocommunication Conference (WRC-23) in Dubai in late 2023. The current definition of UTC was adopted in CGPM Resolution 2 in 2018, followed by the signing in 2020 of a Memorandum of Understanding between BIPM and ITU, outlining the scope of mutual cooperation. Thus, and as a note from the Working Party to the Director emphasizes, establishing UTC is not a spectrum regulation task.

CGPM, in fact, took a decision on a continuous reference time scale in November 2022, supporting the abolition of the leap second. The remaining work, such as ITU cooperation with international organizations and updates to Recommendation ITU–R TF.460, falls under the responsibility of relevant ITU–R working groups.

As part of the ongoing preparations for WRC-23, the ITU Radiocommunication Bureau held a special session with BIPM on Resolution 655 (WRC-15) at ITU headquarters in Geneva, Switzerland. The session, taking place during the 2nd ITU Inter-Regional Workshop on WRC-23 Preparation, sought to gather the views of regional organizations on the issue, as well as sharing the current situation in each region, enabling all regions to move forward together and better meet user expectations.

The various studies undertaken — along with discussions at the preparatory session (CPM23-2) and in Working Party 7A — will pave the way for the revision of Resolution 655 at WRC-23.

The aim, ultimately, is to meet the needs of users as we approach the middle of the 21st Century.

> *"CGPM took a decision on a continuous reference time scale in November 2022."*

Resolutions of the General Conference on Weights and Measures

A decision on a continuous reference time scale was taken in November 2022.

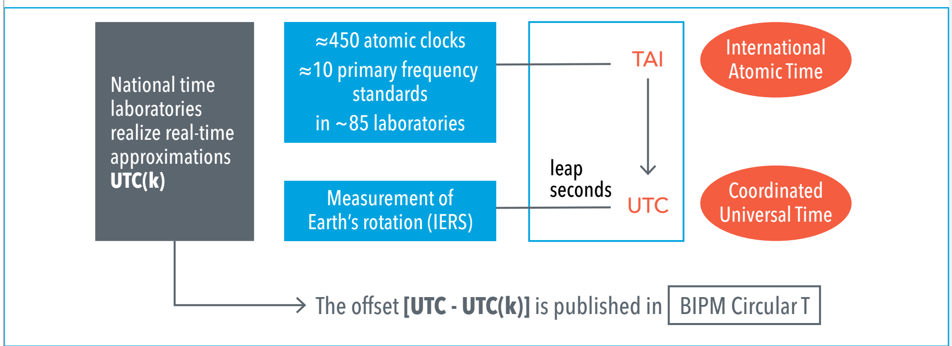
Download
(See Resolution 4 on page 23)

Coordinated Universal Time: An overview

Patrizia Tavella, Director, Time Department, BIPM

Coordinated Universal Time (UTC) is the worldwide reference time scale computed by the *Bureau international des poids et mesures* (BIPM) – the international organization dealing with matters related to measurement science and measurement standards.

UTC is based on about 450 atomic clocks, which are maintained in 85 national time laboratories around the world. The clocks provide regular measurement data to BIPM, as well as the local real-time approximations of UTC, known as UTC(k), for national use (see figure).



Source: BIPM

> *UTC is based on about 450 atomic clocks, which are maintained in 85 national time laboratories around the world.*
>
> Patrizia Tavella

The scale unit, the second, and the reference time scale UTC are defined and realized under the authority of the General Conference on Weights and Measures (CGPM), where 64 Member States and 36 Associate States and economies are represented.

The International Earth Rotation and Reference Systems Service (IERS) determines and publishes the difference between UTC and the Earth rotation angle indicated by UT1. Whenever this difference approaches 0.9 seconds, a new leap second is announced and applied in all time laboratories.

UTC and the UT1-UTC difference are transmitted by several time and frequency services regulated by the ITU Radiocommunication Sector (ITU-R – one of three Sectors of the International Telecommunication Union).

"From the perspective of managing complex systems, the application of the leap second on all satellite clocks at the same instant is a risk."

How BIPM obtains UTC

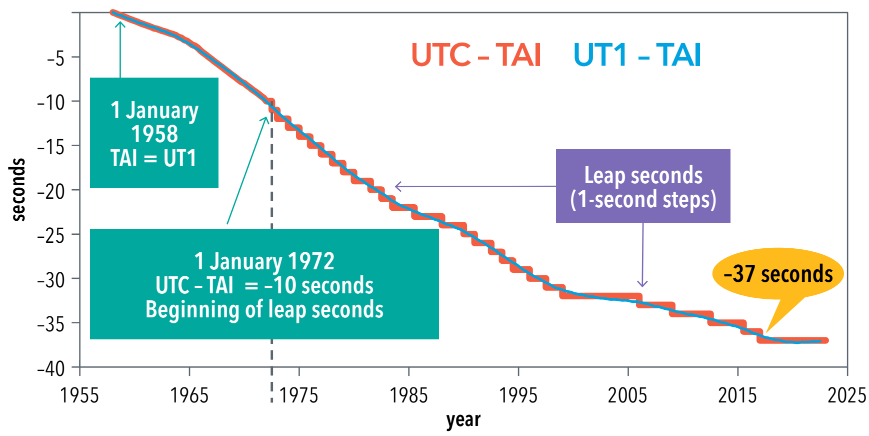
BIPM first computes a weighted average of all the designated atomic clocks to achieve International Atomic Time (TAI). The algorithm for computing TAI is complex, involving estimation, prediction and validation for each type of clock.

Similarly, measurements to compare clocks at distance are based either on global navigation satellite systems (GNSS) or on other techniques, such as two-way satellite time and frequency transfer, or via optical fibres. These all need to be processed to compensate for the delay due, for example, to the ionosphere, the gravitational field, or the movement of satellites.

Ultimately, UTC is obtained from TAI by adding or removing a leap second as necessary and maintaining the same ticking of the atomic second.

UTC's alignment with Earth's irregular rotation

In the 1970s, at the beginning of the atomic clock era, it was agreed that UTC be kept in alignment with the irregular rotation of the Earth, as UTC allowed an estimation of the Earth rotational angle UT1 with a 0.9 second tolerance. This was largely required for navigation systems based on celestial observations. At the outset, UTC was corrected in very small time and frequency steps. From 1972 onward, entire leap seconds were used (see figure).



This figure shows the offset of UTC and UT1 with respect to International Atomic Time (TAI) since the beginning of atomic time. TAI and UTC were set in agreement with UT1 in 1958.

UTC = Coordinated Universal Time

UT1 = Universal Time 1

TAI = International Atomic Time

Source: BIPM

Tech companies using leap-second alternatives

The application of the leap second follows the sequence of second labelling as shown below. An inserted leap second is labelled as 23:59:60 – a clock-time unforeseen in most modern, digital systems.

This discrepancy caused the proliferation of ad hoc methods that are increasingly being used as alternatives to the leap second.

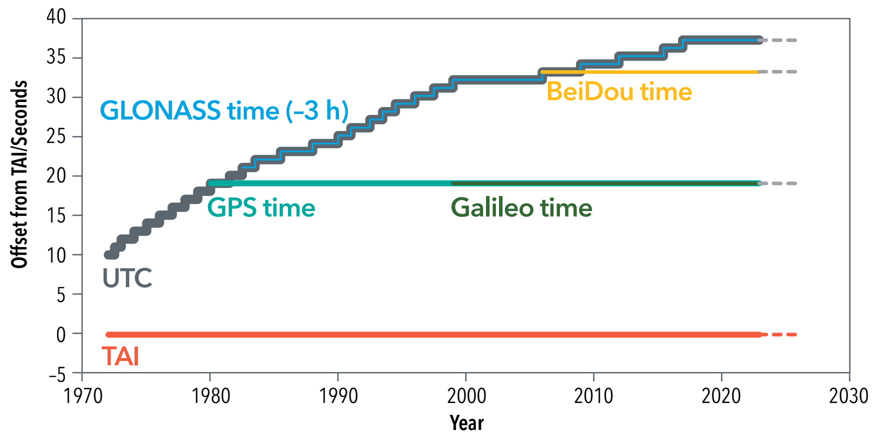
Google for example "smears" the additional second over the previous 24 hours, Facebook over the subsequent 18 hours, Microsoft over the last two seconds, and Alibaba over an interval of 24 hours centred on the leap second.

23:59:59
23:59:60
00:00:00

Risks associated with leap seconds

From the perspective of managing complex systems, the application of the leap second on all satellite clocks at the same instant is a risk. This is why most global navigation satellite systems (excluding GLONASS) opted to synchronize their clocks and time scale with UTC at the outset, without adding any leap seconds.

Today, consequently, GPS time is ahead of UTC by 18 seconds. The same applies for Galileo time, while BeiDou time is ahead by four seconds (see figure).



Source: BIPM

This figure illustrates offsets between UTC, the internal time scales in global navigation satellite systems, and TAI.

This situation causes confusion among users on the day a leap second is applied. It also gives rise to concerns about the risk of anomalies that could undermine the reliability of critical national infrastructure.

Keeping UTC in alignment with Earth's rotation

The 27th meeting of the General Conference on Weights and Measures, held in November 2022, decided to maintain the existing process to keep UTC in alignment with the Earth's rotation. The decision, however, envisages a larger tolerance limit than nine tenths of a second – with correspondingly larger but less frequently needed adjustments – to guarantee UTC's continuity for at least the next 100 years.

BIPM is currently working with ITU–R and other organizations on a new process, expected to come into force in 2035. This would include a newly identified tolerance value for the UT1-UTC offset, to ensure UTC remains efficient and effective in serving current and future timing applications.

"BIPM is currently working with ITU-R and other organizations on a new process, expected to come into force in 2035."

Today's prevailing time scales

Vadim Nozdrin, Counsellor, ITU Radiocommunication Sector Study Group 7 – Science Services

> *Time needs to be defined in a standard way and synchronized worldwide with extreme accuracy.*
>
> Vadim Nozdrin

While any event can be defined by three spatial coordinates and one time coordinate, time needs to be defined in a standard way and synchronized worldwide with extreme accuracy. A time scale is essentially an ordered, and correspondingly numbered, collection of points on a scale.

Today, four time scales are used to a greater or lesser degree:

- **UT1** – Universal Time
- **ET** – Ephemeris Time
- **TAI** – International Atomic Time
- **UTC** – Coordinated Universal Time

Universal Time or **UT1** is determined from observation of the Earth's rotation. It is proportional to the rotation angle of the Earth on its axis. The coefficient of proportionality is selected so that 24 hours in UT1 is close to the average duration of a day, and the phase is determined such that zero hours UT1 corresponds to mean midnight at the Meridian Line in Greenwich, UK.

A UT1 second is understood as a 1/86 400th part of the average solar day. Until 1960, this equalled one second in the international system of units (SI).

UT1, calculated and maintained by the International Earth Rotation and Reference Systems Service (IERS – formerly the International Earth Rotation Service), was the world's generally accepted reference time scale until 1972.

Astronomers, however, have proven that a tropical year – understood as the interval between two consecutive passages of the sun through the vernal equinox – offers greater stability of time intervals than a day. In other words, time is maintained more accurately by using the Earth's orbital movement around the sun than by using the Earth's rotation.

Ephemeris Time or **ET** is determined using the value of the Sun's mean longitude. It was set so that UT1 and ET approximately coincided in the year 1900.

A second of ET was determined as 1/ 31 556 925.9747th of the tropical year on 31 December 1899 (or at 12 hours ET on 0 January 1900 by BIPM's technical definition). This was used as the SI unit for the second from 1960 to 1967.

"Universal Time or UT1 is determined from observation of the Earth's rotation."

Keystone/SPL/Detlev Van Ravenswaay

International Atomic Time or **TAI**, unlike the previous two time scales, is based on a time interval determined by a physical phenomenon. The International Time Bureau (*Bureau international de l'heure* – BIH) coordinates this time standard through atomic clocks working in national laboratories worldwide.

The atomic second has been the SI unit of time since 1967. It is defined as the duration of 9 192 637 770 periods of radiation corresponding to the transition between two hyperfine levels of the basic structure of a caesium-133 atom.

TAI was officially agreed to coincide with UT1 at a starting point on 1 January 1958. Since then, atomic time is determined by the Time Section of the International Bureau of Weights and Measures (*Bureau international des poids et mesures* – BIPM), which collects and processes the times kept by around 450 atomic clocks located in 85 countries.

Yet the idea soon arose to unify different time scales to increase accuracy. This led to the adoption of a new, coordinated global time standard starting in 1972.

Coordinated Universal Time or **UTC** is determined by the following system of equations:

$$\mathbf{UTC(t) - TAI(t) = \mathit{n}\ s}$$

(where n is a whole number, currently n = 34 s)

$$\mathbf{|UTC(t) - UT1(t) < 0.9\ s|}$$

But the variations in the Earth's rotation speed result in a divergence between UT1 and TAI. In such cases, the IERS may decide to regulate the second in relation to the predicted deviation between the time scales. Leap seconds are, accordingly, added – or potentially subtracted – at the end of a month.

> *“TAI was officially agreed to coincide with UT1 at a starting point on 1 January 1958.”*

Keystone/SPL/Detlev Van Ravensway

Managing deviations

Although the UTC standard time scale is calculated and distributed by BIPM, users worldwide have access to local UTC values established through national laboratories (UTC(k)), of which there are some 85 worldwide, coordinated both with UTC and among themselves.

The local labs represented by UTC(k) provide the reference standard in their respective territories by means of various systems. These include broadcasting in SFTSS (standard frequency and time signal service) and SFTSSS (standard frequency and time signal-satellite service); via broadcasting satellites; via fixed, radionavigation and meteorological satellite services; and also on terrestrial networks over optical fibre or coaxial cable.

The International Telecommunication Union (ITU) plays a key role in the establishment and global distribution of standard-frequency and precise time signals. The ITU Radiocommunication Sector (ITU–R) recommends that all standard-frequency and time-signal emissions conform to UTC.

BIPM stipulates that the maximum deviation between UTC and UTC(k) must not exceed ±1 millisecond. For radiocommunication purposes, ITU–R recommends a narrower margin of ±100 nanoseconds.

“ITU-R recommends that all standard-frequency and time-signal emissions conform to UTC.”

Keystone/SPL/Detlev Van Ravenswaay

Time scales

Universal Time

Universal time, or **UT**, is a general designation for time scales based on the rotation of the Earth.

For applications requiring precise timekeeping, where variations of even a few hundredths of a second cannot be tolerated, specific forms of UT must be specified:

UT0 is the mean solar time of the prime meridian obtained from direct astronomical observation.

UT1 is UT0 corrected for the effects of small movements relative to the Earth's axis of rotation (polar variation). UT1 corresponds directly with the Earth's angular position in diurnal rotation, and is the form recommended by ITU for radiocommunication purposes (Rec. ITU-R TF.460).

UT2 is UT1 corrected for the effects of a small seasonal fluctuation in the Earth's rate of rotation.

Definitions of these terms and the concepts involved are available in the publications of the IERS (Paris, France).

International Atomic Time

TAI (International Atomic Time), based on on the second (SI) as realized on the rotating geoid, is maintained by BIPM on the basis of clock data supplied by cooperating establishments. It is a continuous scale, e.g. in days, hours, minutes and seconds from the origin 1 January 1958 (adopted by the CGPM 1971).

Coordinated Universal Time

UTC (Coordinated Universal Time) is maintained by BIPM, with assistance from the IERS, which forms the basis of a coordinated dissemination of standard frequencies and time signals. While it corresponds exactly in rate with TAI, they differ by an integer number of seconds.

The UTC scale is adjusted by the insertion or deletion of seconds (positive or negative leap-seconds) to ensure approximate agreement with UT1.

Source: Recommendation ITU-R TF.460

Adobe Stock

Synchronization and the impact of UTC discontinuities

Stefano Ruffini, Rapporteur, Question 13/15, ITU-T Study Group 15 and Silvana Rodrigues, Senior Principal System Engineer, Huawei

Stefano Ruffini

Silvana Rodrigues

Accurate synchronization is fundamental to effective telecommunication network operations.

Synchronization is more important than ever in today's 5G networks and will be even more so in future mobile networks, where emerging radio technologies and network architectures support increasingly demanding use cases, such as time-sensitive networking for automated vehicles or controlling robots in smart factories.

Time synchronization

Time-synchronization references in telecommunications sometimes involve continuous time scales, as opposed to time scales using leap seconds.

The ITU Telecommunication Standardization Sector (ITU-T – *one of three Sectors of the International Telecommunication Union*) includes an expert group on network synchronization and time distribution performance (ITU–T Study Group 15 Question 13).

Applications discussed in Question 13/15 generally require continuous time scales. The related performance requirements, in fact, are based on a continuous ideal reference timing signal (e.g. when expressed in terms of the metrics specified in ITU–T Recommendations G.810 and G.8260).

Accurate synchronization is fundamental to effective telecom network operations.

Stefano Ruffini and Silvana Rodrigues

Synchronization types

Different types of synchronization are applicable in telecommunications:

- **Frequency synchronization** – significant events occur at the same frequency.
- **Phase synchronization** – significant events occur at the same instant.
- **Time synchronization** – significant events occur at the same instant and sharing a common time scale and epoch.

G.810: Definitions and terminology for synchronization networks

G.8260: Definitions and terminology for synchronization in packet networks

Frequency synchronization typically follows Coordinated Universal Time (UTC), also known as the international reference time scale. A note in ITU–T Recommendation G.810, for example, says:

"The reference frequency for network synchronization is the frequency which generates the UTC time scale."

A continuous time scale for frequency synchronization

The use of a continuous time scale is important for applications using frequency synchronization where phase leaps can have a negative impact on performance.

This is also true in the case of time synchronization. In fact, requirements currently discussed under Question 13/15 are mainly derived from 3GPP (3rd Generation Partnership Project) specifications, where the use of a continuous time scale is explicitly required.

The use of a continuous time scale is important for applications using frequency synchronization where phase leaps can have a negative impact on performance.

One example is specification TS 38.401, which states:

"... continuous time without leap seconds traceable to common time reference for all gNBs in synchronized TDD-unicast area. In the case the TDD-unicast area is not isolated, the common time reference shall be traceable to the Coordinated Universal Time (UTC)."

gNB = 5G (NR) Node B.

TDD = time division duplex

Interference risk with unsynchronized base stations

Time division duplex (TDD) signals can be transmitted in uplink or downlink according to a specific timeslot allocation. This requires UTC traceability to coordinate the transmission of the start of radio frames between adjacent base stations, thereby preventing interference or, in the worst case, service stoppage.

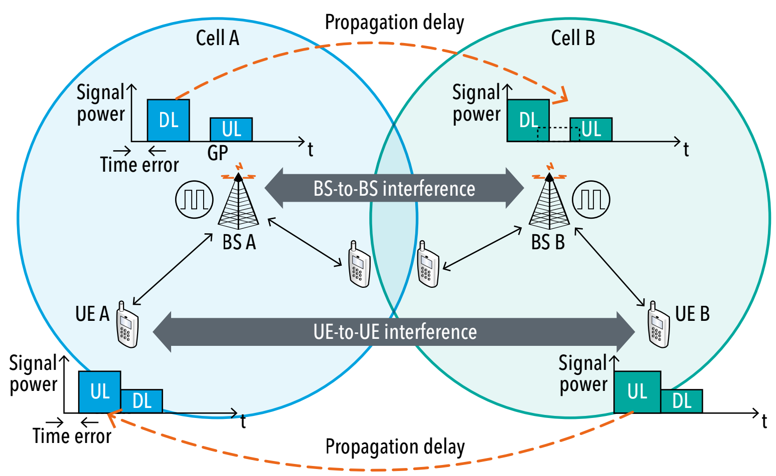
Station-to-base interference can occur if base stations are not properly synchronized, and the time synchronization error exceeds some predefined limits. (See the two figures below for an example related to downlink and uplink switching.)

ITU-T Recommendation G.8271, Appendix VI (Time synchronization aspects in TDD based mobile communication systems), notes:

"Given the 3GPP requirement for a continuous timescale, the actual implementation in this case could make use of the content of the distributed UTC information that is not impacted by leap seconds, e.g., GPS time in case the reference is carried by a GPS signal."

> *"The GPS time scale has become widely used in telecommunication applications as the only leap-second-free time scale available globally."*

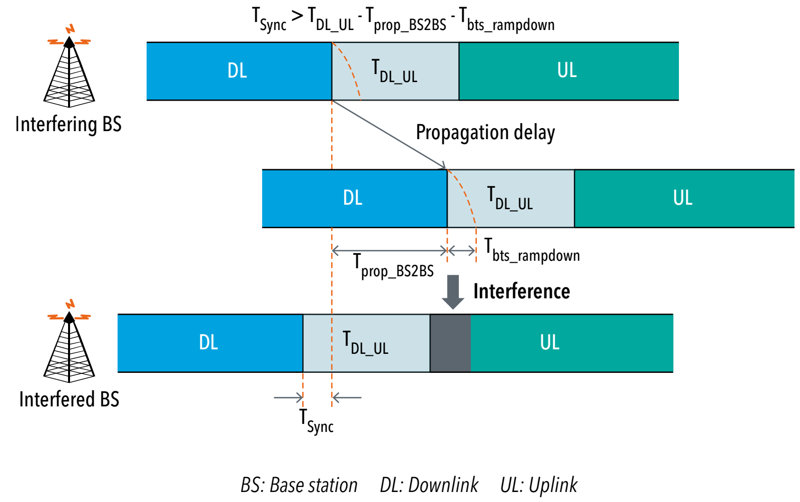
Overview of interference patterns in time division multiplexing systems



BS: Base station DL: Downlink GP: Global positioning UE: User equipment UL: Uplink

Source: Appendix 6, Figure VI.2/G.8271

Base station to base station interference at downlink to uplink switching point



Source: Appendix 6, Figure VI.5/G.8271

GPS time without leap seconds

The Global Positioning System (GPS) time scale has become widely used in telecommunication applications as the only leap-second-free time scale available globally.

Current GPS solutions avoid clock disturbances by making use of time scales and information that do not include leap seconds. The precision time protocol (PTP) time scale, for example, is based on international atomic time (TAI) or GPS time.

For applications requiring standard "time of day" information (e.g., for charging, timestamping of alarms, etc.), UTC time may also need to be recovered. Such applications must be ready to address the occasional, sudden "time jump".

> *"Telecommunications could benefit from measures to define a continuous UTC without additional leap seconds."*

UTC without leap seconds

Telecommunications could benefit from measures to define a continuous UTC without additional leap seconds — or where periodic adjustments are performed over sufficiently long periods to avoid impact on normal network operation.


Adobe Stock

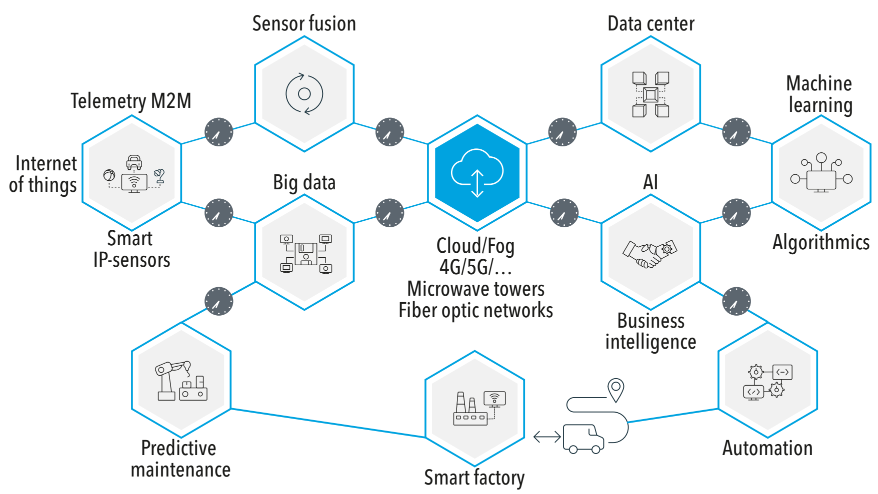
The impact of UTC on Industry 4.0

Tomasz Widomski, Co-founder, Elproma

The global economy depends on the global navigation satellite system (GNSS), which provides the coordinated universal time (UTC) reference to critical modern infrastructure worldwide.

> *The global economy depends on GNSS, which provides the UTC reference to critical modern infrastructure worldwide.*
>
> Tomasz Widomski

Global supply chain



Source: *ITFS 2020*

This includes distributed smart grids, 5G telecom networks, traffic-control systems, and autonomous vehicles. It supports broadcasting services, financial markets, and smart cities, as well as Industry 4.0 systems migrated to the cloud.

> *"Close interdependence of entire Industry 4.0 systems have given rise to a need for the urgent suspension of future leap seconds."*

Leap-second challenges for Industry 4.0

The non-continuous nature of UTC, which requires periodically adding a leap second, affects all countries and all segments of every economy. It poses a particular problem for the stability and cybersecurity of Industry 4.0, the modern industries and services reliant on distributed system architecture.

Issues with the leap second have existed for years. But exponentially growing automation and the close interdependence of entire Industry 4.0 systems have given rise to a need for the urgent suspension of future leap seconds.

The situation is complicated by the lack of leap-second servicing standards, poor dialogue between the information technology (IT) and time metrology communities, the diversity of implementation for GNSS receivers, and the different approaches to service provision among global satellite navigation systems such as the Global Positioning System (GPS), Galileo, the Global Navigation Satellite System (GLONASS) and BeiDou, and regional systems like the Indian Regional Navigation Satellite System (IRNSS).

Disruption scenarios

The problems arising from adding leap seconds to UTC can include:

1. **Time discrepancies** in distributed systems, where the validity of data is determined by the difference between timestamps for the remote sensor and the local receiving server of the centralized management. This can lead to the acceptance of invalid data (wrongly computed delay) and, consequently, to the wrong Industry 4.0 predictive maintenance. Such risks will increase with the growing adoption of time-sensitive networking (TSN), time-coordinated computing (TCC) and in future, low-latency networking.

2. **Failures of firmware software** for Internet of things (IoT) and IT devices based on Windows, Linux, or Unix operating systems. Every sensor or appliance produced today has firmware based on one of those systems. The unexpected peaks in time introduced by the leap second are dangerous for the stability of the operating system kernel. They disturb the low-level event chronology that governs concurrency management and low-level system processes. Mismatches in chronology can result in "kernel panic" – a computer error from which an operating system cannot quickly or easily recover.

In such scenarios, the UTC leap second can trigger a large-scale domino effect, producing blackouts in power systems and telecommunications, as well as disrupting railways, air-traffic control, and Industry 4.0 process automation. Sooner or later, such failures will occur unless a leap second suspension is put into effect.

Industry risks

Today, we face the likelihood of a future leap second in UTC needing to be, for the first time in history, negative. In the working environment of Industry 4.0 production, this will be a dangerous experiment.

While the UTC leap second is the leading risk, it is not the only risk for Industry 4.0. Since the very first commercial GPS receiver was released in the 1990s, several hundreds of millions of commercial GNSS receivers have been deployed and used as UTC references. Yet they each calculate UTC a fraction of a second differently, due to variations in internal algorithms and depending on the current GNSS constellation they are using.

Accuracy in UTC synchronization also depends on weather conditions, quality of antenna installation, interferences, and cybersecurity, including GNSS jamming/spoofing. All these are further subject to the risk of internal GNSS errors (e.g., the GPS SVN23 13.5 microsecond (μs) error in January 2016) or overflows, such as the GPS week number rollover every 19.7 years.

Other GNSS constellations are similarly imperfect.

Synchronization for cybersecurity

Clearly, we need a security paradigm change, starting with a recognition of precise time synchronization as an important part of Industry 4.0 cybersecurity.

A good example is US Presidential Executive Order EO13905: *Strengthening National Resilience Through Responsible Use of Positioning, Navigation, and Timing Services*, released in February 2020. It opened the way for new low-Earth orbit (LEO) commercial satellite constellations. Crucially, it has also promoted computer-network synchronization protocols, such as the network time protocol (NTP) and precision time protocol (PTP) IEEE1588, both of which disseminate UTC from the national metrology institutes.

While the network time protocol was innately designed to use UTC, the precision time protocol can work with any time scale, including the coherent international atomic time (TAI) equivalent.

“We need a security paradigm change, starting with a recognition of precise time synchronization as an important part of Industry 4.0 cybersecurity.”

Adobe Stock

Oleg Obleukhov

Ahmad Byagowi

Time synchronization in data centres

Oleg Obleukhov, Production Engineer, Meta and
Ahmad Byagowi, Research Scientist, Meta

Time synchronization is extremely important for almost every software application within a data centre. Time is used for correlating and ordering simultaneous events between millions of servers.

In security, reliable timekeeping is essential for cache expiration and invalidation, short-lived certificates, and intrusion detection. Time synchronization helps engineers correlate log entries where Coordinated Universal Time (UTC) is often used.

As transaction throughput constantly increases, time differentiations of even just a couple of milliseconds can cause serious issues. How time reaches and propagates within the data centre, therefore, is crucial.

Global navigation satellite systems

There are different ways to propagate accurate time to data centres. In many cases, it starts with receiving a radio-frequency broadcast from global national satellite system (GNSS) constellations such as GPS, GLONASS, Galileo and BeiDou via special devices called time appliances.

Interaction between GNSS satellites and time appliances

Source: Oleg Obleukhov and Ahmad Byagowi, Meta

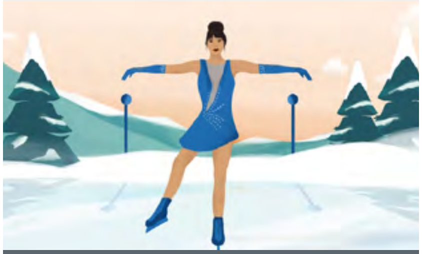
"Time synchronization is extremely important for almost every software application within a data centre."

Ahmad Byagowi and Oleg Obleukhov

Due to irregularities in the Earth's rotation, the difference between monotonically increasing International Atomic Time (TAI) and UTC constantly fluctuates, eventually reaching a ±500 millisecond limit. At this point the International Earth Rotation and Reference Systems Service (IERS) issues an instruction for a leap second to be either added or removed from UTC.

This is further complicated by each constellation implementing its own operational time and additional conversion steps to UTC. For example, GPS time has a constant 19-second offset from TAI, while GLONASS is based on UTC.

Such complexity often falls on time appliances and, as with any other moving parts, occasionally causes problems.



Is it time to leave the leap second in the past?

Read the article.

Open source time appliance

Under Meta's Open Compute Project, we have started a Time Appliances Project workstream dedicated to developing the Open Source Time Appliance. We wanted to liberate the industry from proprietary solutions, facilitate transparency, and significantly reduce the cost of the time appliance.

While implementing open-source time-appliance software, we had to address a complex logic handling different constellations and leap second indicators to produce TAI. We published an in-depth article detailing our approach, motivations, and the process of building our time appliance.

Once the time appliance is synchronized, we are ready to propagate time across a packet-switched network.

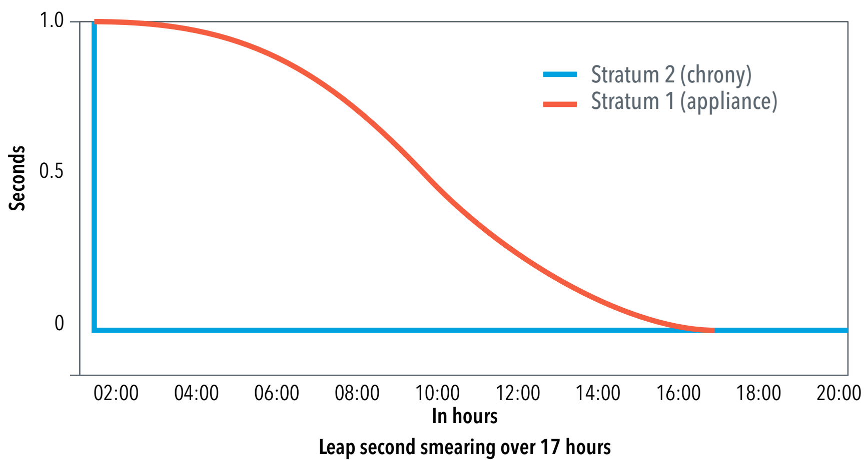
Network time protocol

Network time protocol (NTP) is one of the most common types of time synchronization within data centres. It is a very reliable, battle-tested technology. Most servers and end-user devices around the world rely on NTP to keep their time up to date.

At Meta, we run a state-of-the-art low-jitter NTP, which we constantly validate using extremely precise and accurate timing equipment. NTP can reliably bring down synchronization to hundreds of microseconds with a window of uncertainty under 100 milliseconds. This leaves two options to handle a leap event: stepping the clock or smearing.

Stepping is known to cause issues, making smearing (a technique of spreading or "smearing" time over a period of hours to account for leap seconds) the preferred option in most cases. Our equipment allows us to measure the impact of leap-second smearing down to a few nanoseconds (see figure).

Offset from "true time"



Source: Oleg Obleukhov and Ahmad Byagowi, Meta

Some components for building a time appliance

OCP
Tioga Pass

NVIDIA Mellanox
ConnectX-6 Dx

Facebook
Time Card

Source: Oleg Obleukhov and Ahmad Byagowi, Meta

From these measurements we know the sizes of adjustments can reach tens of microseconds per second – large enough to crash software unless a monotonic clock is used. This puts additional pressure on our engineering teams and frequently causes issues within different parts of the infrastructure.

Similar pressures are felt across the digital industry. Given such challenges, we are not looking forward to the first-ever negative leap second.

Precision time protocol

Even though network time protocol is fine for most user applications today, we find it increasingly difficult, or even impossible, to use for distributed storage systems, where demanding applications require much tighter guarantees.

This is why companies like Meta deploy additional synchronization solutions such as precision time protocol – pushing the window of uncertainty down to nanoseconds.

This level of precision makes it simply impossible to smear a leap second safely. Therefore, precision time protocol is mostly used with TAI. When conversion to UTC is required, it has to be performed separately for each client, which means degrading the window of uncertainty by several orders of magnitude.

It's time

We support the decision of the International Bureau of Weights and Measures' (BIPM) to discontinue the leap second in practice by 2035.

Fixed UTC will slowly diverge from solar observed time, but it will increase the stability of critical systems. Having a leap hour or a daylight-saving time correction once every few millennia will be a much safer and more sustainable approach for everyone.

"We support the decision of BIPM to discontinue the leap second in practice by 2035."


Adobe Stock

The UK's National Timing Centre programme

Helen Margolis, Head of Science for Time and Frequency, National Physical Laboratory, UK

> *We rely on increasingly accurate timing signals to sustain critical services such as telecoms, power grids, banking and transportation.*
>
> Helen Margolis

Time is sometimes called the invisible utility. We rely on increasingly accurate timing signals to sustain critical services such as telecommunications, power grids, banking and transportation.

However, many organizations are unaware of their dependence on time or lack an understanding of where that time comes from.

Over-reliance on GNSS

In most cases, timing signals come from global navigation satellite systems (GNSS). But those signals are weak, making them vulnerable to jamming or spoofing, or to natural interference from phenomena such as solar storms. This vulnerability, coupled with low awareness of the extent to which critical infrastructure depends on GNSS, poses a significant risk.

In the United Kingdom (UK), this risk was articulated in the 2018 Blackett review (Satellite-derived time and position: a study of critical dependencies) and added to the National Risk Register in 2020. Both the review and the register have made clear the necessity of taking steps to increase resilience to GNSS disruption, including the adoption of backup systems where appropriate.

UTC(NPL) – an alternative source of time

The National Physical Laboratory (NPL), as the UK's National Metrology Institute, maintains the UTC(NPL) time scale – the only realization of coordinated universal time (UTC) in the UK – and disseminates this to users.

Our current services, though, are limited either in the accuracy they can deliver or in their geographical reach. The MSF radio time signal and Internet time service are relatively imprecise, while our fibre-based NPL*Time*® service for the financial sector is only available in a restricted area of the UK.

To meet increasingly demanding user requirements and reduce overreliance on GNSS in critical national infrastructure, NPL is leading a programme to significantly enhance timing infrastructure and capabilities across the UK.

The National Timing Centre programme

At the heart of this programme is the construction of a new, more resilient time scale, which once fully commissioned will become the source of UTC(NPL).

It is designed as a mesh of four geographically distributed, linked sites. Each will contain several hydrogen masers (electromagnetic wave emitters), together with associated signal measurement, frequency steering and distribution equipment, allowing for the implementation of several time-scale realizations. Inter-site time transfer links will keep all time-scale realizations aligned to the one designated as UTC(NPL), using multiple methods to ensure resilience.

UTC(NPL) itself will be steered to keep it within defined time and frequency offsets of UTC, assisted by caesium fountain primary standards within the mesh. Switching between different time-scale realizations will be possible when necessary either within the same site or at different sites. Software is being developed to monitor, control and automate the operation of the new infrastructure.

"To meet increasingly demanding user requirements and reduce overreliance on GNSS in critical national infrastructure, NPL is leading a programme to significantly enhance timing infrastructure."

A caesium fountain built by NPL

Learn more.

Stimulating innovation

Time and frequency signals from our existing UTC(NPL) time scale are also being made available to industrial and academic users through new innovation nodes located at the universities of Strathclyde, Surrey and Cranfield.

In partnership with Innovate UK, we are supporting research into time and frequency generation, dissemination and applications, as well as stimulating development of the industrial supply chain. The three innovation nodes, employing different time and frequency transfer methods for their connection to UTC(NPL), could serve as a blueprint for future UK distribution infrastructure.

A continuous time scale for a digital world

The new UK time scale is, of course, designed to handle leap seconds in accordance with international standards. This means it will provide the capability to disseminate leap second information to user access nodes. But not all time dissemination protocols deal properly with leap seconds, and the possibility of a negative leap second – something never experienced before – poses another risk to resilience.

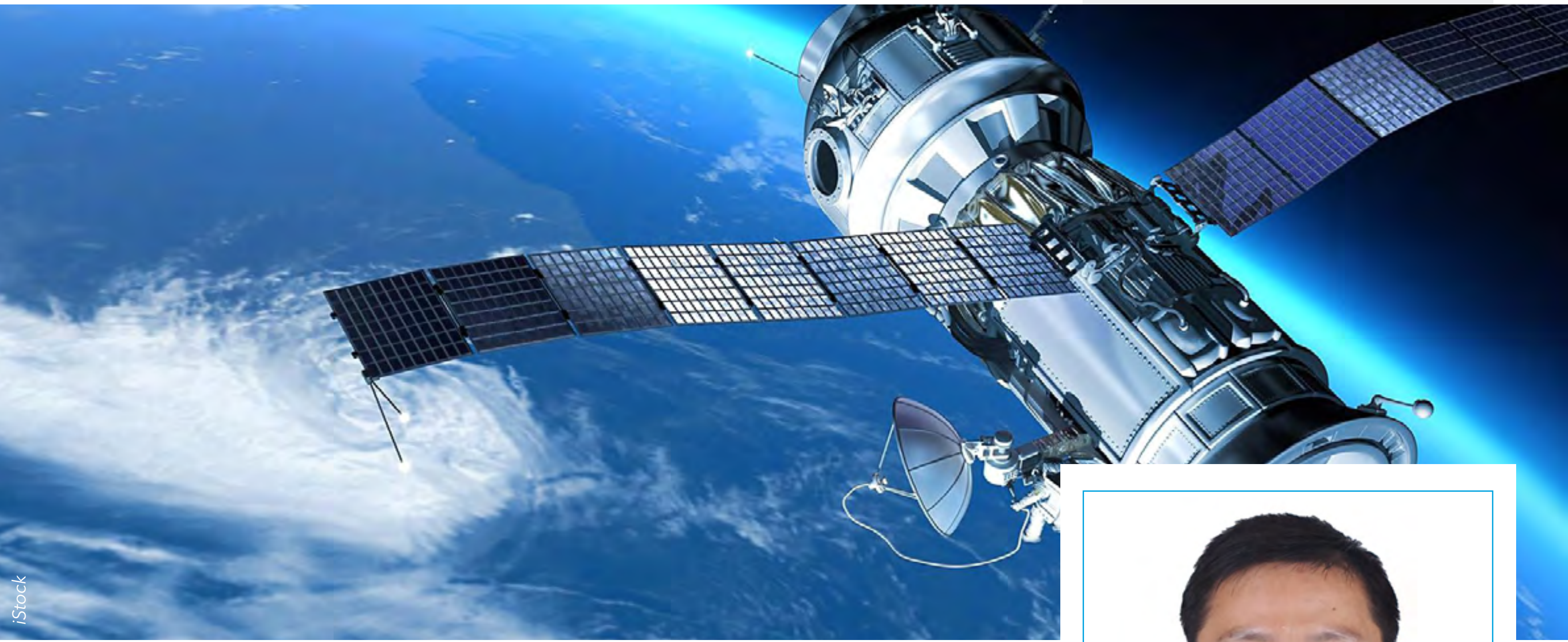
For these reasons, key UK stakeholders think changing to a continuous UTC without leap seconds offers the best route to a resilient precision time scale that supports the modern digital economy.

Future vision

Our long-term ambition is to create a high-accuracy time and frequency backbone running the length of the country. Branches stemming off that backbone would deliver a range of services with different performance levels, some via fibre, some using broadcast technologies.

All these signals would be traceable to UTC(NPL) as the highest point of reference within the UK. The aim is to provide resilient time that users can trust – whoever they are and wherever they are.

“Our long-term ambition is to create a high-accuracy time and frequency backbone running the length of the country.”



iStock

The BeiDou Navigation Satellite System and the UTC leap second

Yuting Lin, Senior Engineer, Beijing Satellite Navigation Center, Yuanxi Yang, Research Fellow, State Key Laboratory of Geo-Information Engineering and Bijiao Sun, Engineer, State Key Laboratory of Geo-Information Engineering, China

Yuting Lin

Yuanxi Yang

Bijiao Sun

A continuous, stable and accurate timing service is a basic requirement for national economic and social development. Today, satellite navigation systems support the most widely used timing service method, offering the highest accuracy and most extensive coverage.

BeiDou's time system

The BeiDou Navigation Satellite System (BDS) has become a vital part of this timekeeping infrastructure, with its third generation BDS-3 reaching completion with final satellite launches in 2020. The BDS constellation now has 45 operational satellites, including 15 BDS-2 satellites and 30 BDS-3 satellites, jointly providing user services. Their timing accuracy is better than 20 nanoseconds, representing a 95 per cent confidence level.

BDS adheres, for its reference time, to BeiDou Navigation Satellite System Time (BDT), which uses the SI (International System of Units) second for continuous accumulation without leap seconds.

The initial epoch of BDT was 00:00:00 on 1 January 2006, Coordinated Universal Time (UTC). BDT relates to UTC as maintained by China's domestic timekeeping laboratory, with the offset between BDT and UTC kept within 50 nanoseconds (modulo 1 second). Leap second corrections between BDT and UTC are broadcast by NAV message.

Since 1972, UTC has been updated 27 times with positive leap seconds, the latest being on 31 December 2016. At present, the difference between UTC and International Atomic Time (TAI) is 37 seconds.

Impact of leap seconds on BeiDou systems

The leap second affects BeiDou users who adopt BDT, rather than UTC, as their time reference, whether for time synchronization, determining orbit measurements, data processing or other purposes.

While space systems are responsible for receiving and forwarding leap-second parameters, their own system is unaffected by leap seconds.

Satellite navigation systems provide time services for critical infrastructure such as electric power, communication, and finance. Given their crucial need for time continuity, frequent leap-second processing would not be conducive to their safe operation.

Today's ground-based systems process the leap second and broadcast via NAV message to their users. Still, generating and inserting such parameters imposes a burden, along with calculation risks in the operational system.

The output time of the BDS receiver after receiving the satellite signal is UTC time. This means the receiver must take account of leap-second correction parameters and correct the time difference.

If leap seconds were cancelled, the time offset (or the integral number of seconds) between BDT and UTC would be pre-set in systems as a fixed constant. This would simplify system operation and application, improve system stability, and be more favourable to the compatibility and interoperability of multiple global navigation satellite systems.

> *"A continuous, stable and accurate timing service is a basic requirement for national economic and social development."*
>
> Yuting Lin, Yuanxi Yang and Bijiao Sun

> *"While space systems are responsible for receiving and forwarding leap-second parameters, their own system is unaffected by leap seconds."*

UTC reform proposals

The impact and risks that arise from implementing such adjustments have led to growing calls for UTC reform and the cancellation of leap seconds. The topic of "the future of Coordinated Universal Time" was submitted to the International Telecommunication Union (ITU) for discussion as early as 1999.

At that time, the Chinese representative to ITU proposed to further study the issue and make a decision after the pros and cons were clear. Relevant countries and organizations subsequently continued discussing the leap second at the World Radiocommunication Conference in 2015, where it was decided to make no changes to UTC before 2023.

At this point, progress in science and technology has made the need for UTC reform urgent.

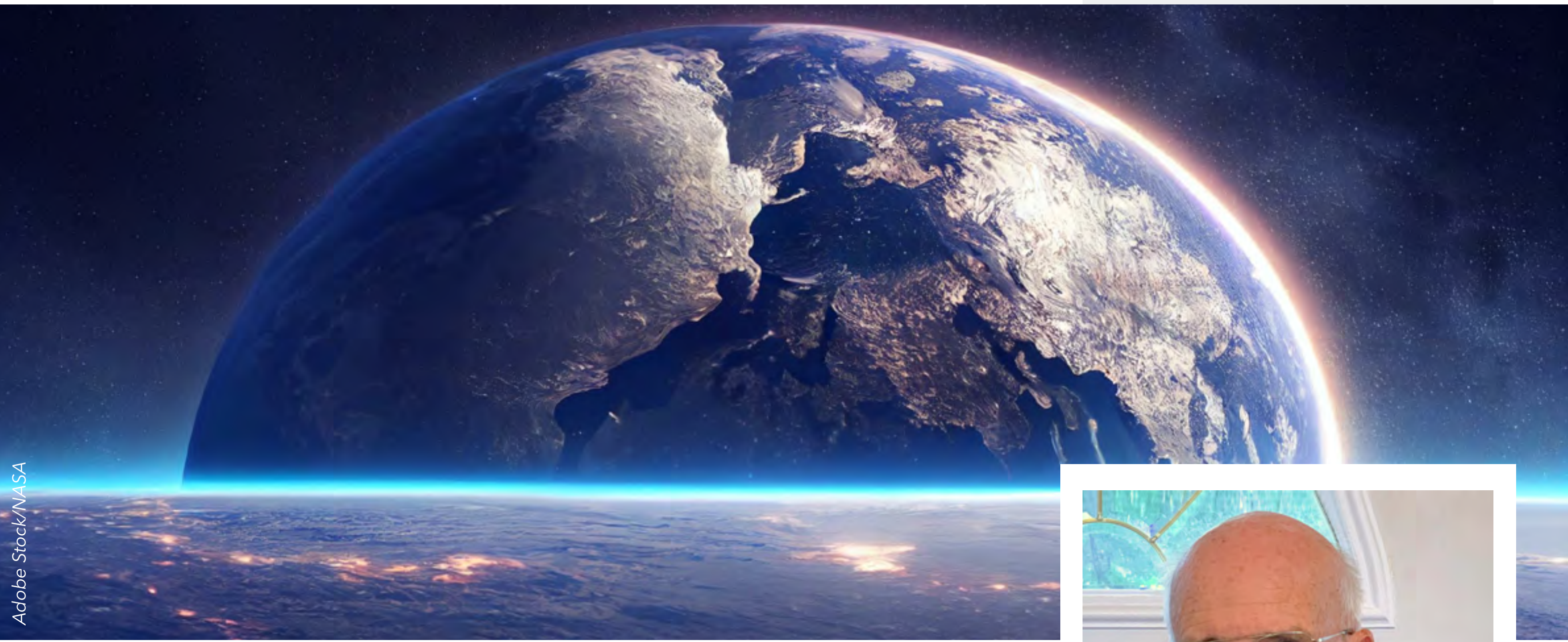
Three key points must be taken into consideration:

1. **A future UTC should be more continuous**, stable, and accurate. As the universal time standard for evolving economies and societies, it should be better adapted to the needs of users and the ongoing development of science and technology.

2. **A new second length is needed**, with the purpose of absorbing the difference between the atomic second length defined by UTC and the physical second length caused by the uneven rotation of the Earth. This would eliminate the need for a leap second for 10 000 years. Prior to the new second length coming into effect, of course, users should be given sufficient time to comprehensively evaluate and upgrade their existing systems and software to avoid possible operational risks.

3. **UTC's connection with Universal Time 1** (or UT1, based on the Earth's rotation) should somehow be maintained. UT1 still prevails in certain fields and industries, such as astronomy, geodesy, and space exploration, to name just a few. The needs of these users, therefore, must also be considered and resolved.

"The progress of science and technology has made the need for UTC reform urgent."



Adobe Stock/NASA

Practical impact on astronomy

Dennis McCarthy, International Astronomical Union Representative to the Consultative Committee for Time and Frequency and BIPM

Astronomical applications that use the current definition of Coordinated Universal Time (UTC) to access UT1 – the Universal Time based on Earth's rotation – would be impacted by any change in the definition of UTC.

The rotation angle of the Earth in a celestial reference system is described by the angle UT1. The current definition of UTC ensures that the difference between UT1 and UTC (i.e., UT1-UTC) remains under 0.9 seconds, which allows easy access to UT1 through UTC for those applications that do not need high precision.

If UTC is redefined, applications that currently use UTC as a low-accuracy representation of UT1 may be compelled to change their strategy, update their basic software, and educate their users about these changes. Any change in the definition of UTC could also present a cause for concern among producers and users of astronomical data.

"Astronomical applications that use the current definition of UTC to access UT1 would be impacted by any change in the definition of UTC."

Dennis McCarthy

These applications include:

- terrestrial telescopes, antennas, and other instruments pointed in precise directions;
- astronomical software and applications that assume the current definition of UTC;
- astronomical data in almanacs and websites employing the current definition of UTC; and
- the provision of observed or predicted values and parameters to describe the orientation of the Earth with respect to astronomical reference systems.

> *"Any existing software and applications that assume UTC is essentially equivalent to UT1 may require modification."*

Pointing of terrestrial telescopes, antennas, and instruments

Astronomical pointing applications that require UT1 with better precision now obtain current and predicted estimates of UT1-UTC from the Internet, GPS or BeiDou to satisfy their needs.

However, the current definition of UTC does not allow for UT1-UTC values to differ by more than nine-tenths of a second. If this changes, much existing software may have to be modified to allow for more digits in UT1-UTC.

Even so, if the current operational needs of telescopes for UT1 are met with the current accuracy of UTC, then the same accuracy requirement would presumably be satisfied within ±1 second in UT1-UTC, in which case software adjustments might be minimal.

Such issues are expected to be resolvable with adequate lead time in the implementation of a new definition of UT1-UTC.

Astronomical software and applications

Similarly, any existing software and applications that assume UTC is essentially equivalent to UT1 may require modification, allowing for corrections to include values of UT1-UTC. Current and predicted approximations of UT1-UTC from the Internet, as well as from GPS or BeiDou, are expected to satisfy this need, but their software and procedures might require modification.

Again, these issues can be resolved with adequate lead time.

Astronomical data in almanacs and websites

Ephemerides (predictive tables of planet, comet, or satellite positions) and predictions of astronomical phenomena are computed using a continuous time scale independent of the Earth's rotation. Consequently, these calculations would be unaffected by any change in the definition of UTC. However, the resulting information may rely on UTC as a reference time.

Adjustments to UTC are unpredictable and are announced only months before their implementation. Astronomical ephemerides for future dates over longer-time spans could become erroneous due to unanticipated UTC adjustments along the way.

Ephemerides expressed in UTC would consequently benefit from removing the leap-second adjustments that contribute to the prediction error in UT1-UTC. In fact, the possibility of this error would be eliminated.

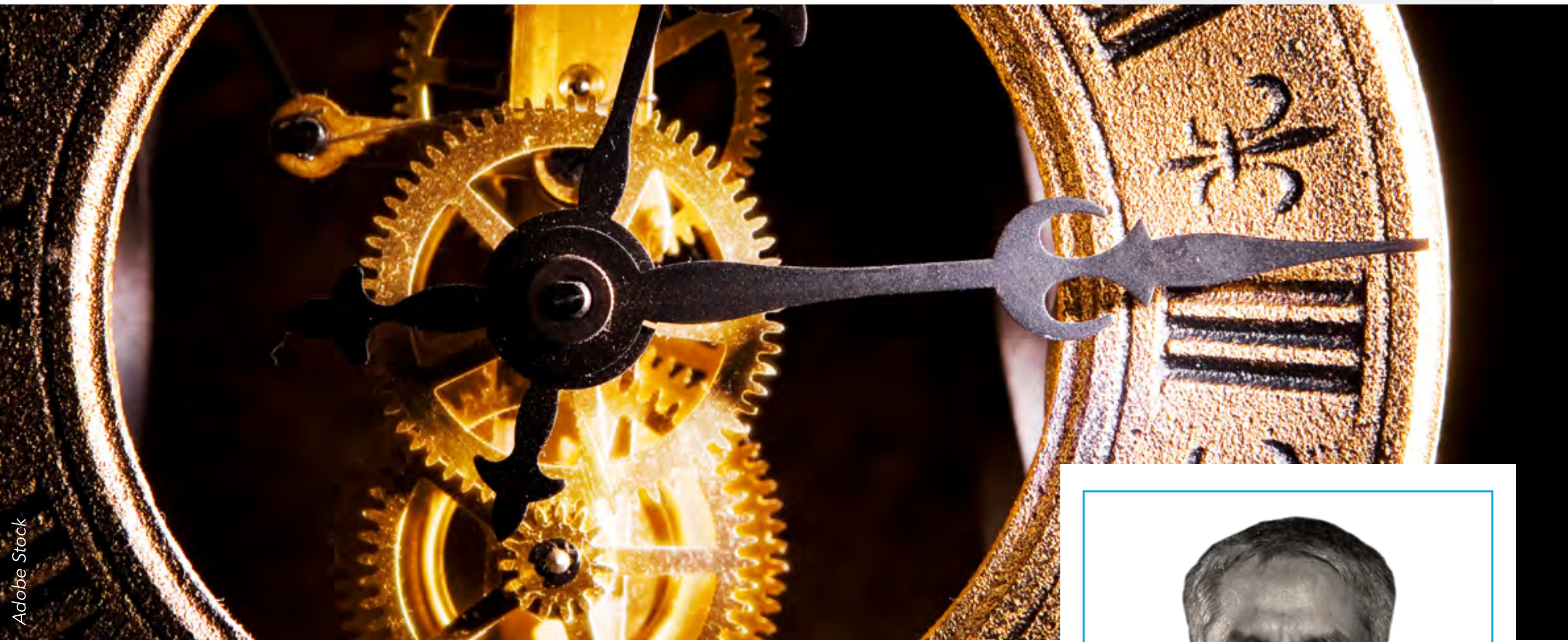
Providing observed and predicted values of UT1-UTC

The International Earth Rotation and Reference System Service (IERS), established by the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG), is responsible for providing observed and predicted values of UT1-UTC. In that capacity, it is responsible for announcing the one-second adjustments to UTC known as "leap seconds."

Proposed changes in the definition of UTC might allow for a difference larger than 0.9 seconds between UT1 and UTC. The role of the IERS, currently focused on announcing leap seconds, would then change. However, a proposed redefinition of UTC would likely increase the importance of IERS activities, with a renewed focus on providing UT1-UTC data, perhaps even on a real-time basis.

In summary, the redefinition of UTC would certainly have an impact on astronomical efforts, but sufficient lead time would allow the astronomical community to adjust to that impact with no disruption in current procedures.

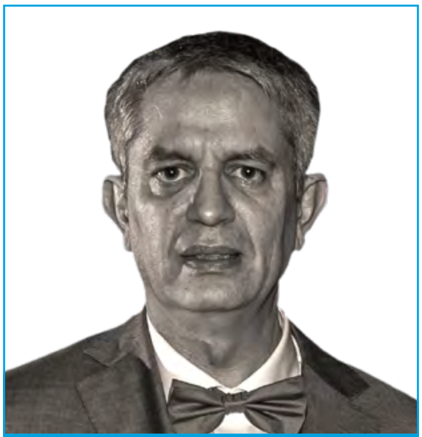
"Proposed changes in the definition of UTC might allow for a difference larger than 0.9 seconds between UT1 and UTC."



Adobe Stock

Dissemination of time: A historical perspective

Christian Bizouard, Astronomer, Paris Observatory (SYRTE) and IERS Earth Orientation Centre



"As early as in the 18th Century, time dissemination was achieved through mechanical clocks, which enabled mobile timekeeping over long distances, especially at sea."

Christian Bizouard

The dissemination of time based on the Earth's rotation, determined by the mean solar time (t) of a reference meridian, is an ancient practice that has evolved with the advancement of technologies and their applications.

As early as in the 18th Century, time dissemination was achieved through mechanical clocks, which enabled mobile timekeeping over long distances, especially at sea. These facilitated the computation of prime-meridian rotation with respect to Greenwich Sidereal Time (GST). A celestial object's right ascension (α) in the local meridian could then determine longitude of the local meridian [$\alpha - GST(t)$], allowing increasingly accurate navigation and maps.

In the 19th Century, time dissemination became crucial for railway timetables. Growing international commerce and communications led to the adoption in 1884 of the Greenwich mean solar time as Universal Time (UT). Still, manmade clocks were not stable enough to be synchronized with the Earth's rotation time, and they had to be adjusted to UT through astronomical observations every few days.

In the early 20th Century, different radio services around the world began broadcasting in local time zones in relation to UT. In 1912, the International Time Bureau (BIH – *Bureau international de l'heure*) at the Paris Observatory began collecting data to maintain UT.

The irregularity of Universal Time

The invention of the quartz clock changed the game in the 1930s, revealing UT's irregularity, with a seasonal variation of about 20 milliseconds (ms). Planetary ephemeris comparisons confirmed further oscillations of up to five seconds in UT over multi-decade periods.

Based on ancient solar eclipse records, the length of a day increases over the long term at the rate of 1.8 milliseconds per calendar year (ms/cy), causing a parabolic decrease in UT as recorded over significant periods.

By the 1950s, the quartz oscillator could be coupled to an atomic resonator for enhanced timekeeping stability. The resulting evidence of instability in the Earth's rotation led to a distinction between traditional astronomical time (UT1) and the more stable UT determined by atomic clocks. International Atomic Time (TAI) was adopted for scientific purposes in 1958. Thirteen years later, the TAI second became the widely accepted time standard for all human activity.

Aligning atomic time with UT1

In 1972, Coordinated Universal Time (UTC) became the widely accepted basis for international timekeeping. UTC is stable like TAI, except it is sometimes shifted by one second to match astronomical reality, or to remain within 0.9 seconds of UT1.

Unadjusted TAI, by contrast, has crept ahead of UT1 by some 27 seconds since 1972. UTC thus maintains an ongoing compromise between the stability of atomic timekeeping and the reality of Earth's days and nights.

In 1987, BIH's astronomical activities became part of the International Earth Rotation Service (IERS), now the International Earth Rotation and Reference Systems Service.

The decision to introduce a one-second shift in UTC requires astronomical monitoring of UT1 with respect to UTC. Nowadays the IERS Earth Orientation Center publishes Bulletin C every six months (on 1 January and 1 July), announcing whether a leap second will be added to UTC on either 30 June or 31 December. UTC was adjusted by 27 leap seconds between 1972 and 2017, of which the occurrences are as unpredictable as the long term multi-decadal length of day variations.

"The invention of the quartz clock changed the game in the 1930s."

Leap seconds

In the last 50 years – 27 leap second have been added to UTC.

What changed in the 1990s?

Until the 1990s, the astronomical pointing needs of navigation were satisfied by the radio broadcasting of UTC, occasionally completed with a UT1-UTC correction to within 0.1 seconds, corresponding to an accuracy of a 45-metre equatorial arc. To this day, such UT1-UTC updates are published when needed by the Paris Observatory in the IERS Bulletin D. But the advent of global navigation satellite systems (GNSS) in the 1990s made previous time precision obsolete. For a real-time positioning to one metre, UT1 must be known within at least 2 milliseconds.

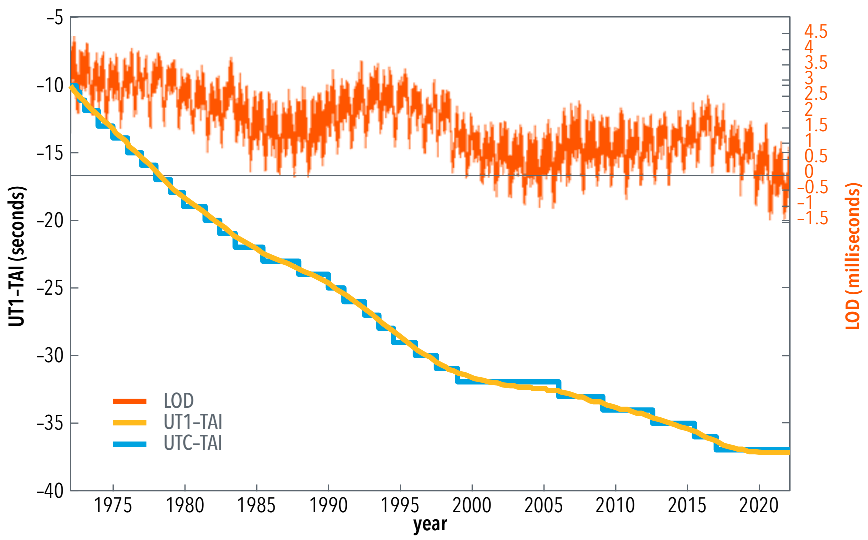
GNSS and other astro-geodetic techniques are based on UT1-UTC values determined by the Very Long Baseline Interferometry (VLBI). Their daily operational values reach a precision of about 30 microseconds (μs), as recorded in IERS Bulletin A, with final values at 7 μs precision published 20–30 days later in the IERS C04 series, Bulletin B.

> *Our days are growing shorter, and with UT1 on average beating a slightly faster second than UTC, the leap second schedule is becoming ever more unpredictable.*

Suppression of the leap second

Over the past 20 years, close synchronization of UT1 with UTC has become largely meaningless, with much of the discussion since 2000 aimed at suppressing the leap second system. Until the 2020s, the length of a day was above 86 400 seconds TAI (see figure), so our days are growing shorter, and with UT1 on average beating a slightly faster second than UTC, the leap second schedule is becoming ever more unpredictable.

Differences UT1−TAI and UTC−TAI since 1972



LOD = length of day offset with respect to 86400 s TAI

When LOD is positive, UT1-TAI decreases. When LOD is negative, UT1-TAI increases.

Source: Christian Bizouard, Paris Observatory

The PNNL Electricity Infrastructure Operations Center (EIOC) provides a realistic control-centre environment for training and advanced technology testing

PNNL

Synchronization of electric power networks

Jeff Dagle, Chief Electrical Engineer, Pacific Northwest National Laboratory (PNNL)

Operating a modern interconnected power system requires uttermost precision. Multiple entities must remain closely coordinated at all times, managing myriad generators and other components synchronized with each other.

System operators keep track of time and use Coordinated Universal Time (UTC) in a variety of advanced applications. Even so, errors in measuring and distributing time will not necessarily result in power system failures. The power grid can operate without a common timing reference.

Nevertheless, advanced applications that rely on accurate and precise time may be disrupted, introducing reliability concerns. This article describes how precision time is used in power system operations, with a special emphasis on the role of UTC.

"In recent decades, the inexpensive and ubiquitous precision time provided by Global Navigation Satellite Systems has enabled advanced measurement."

Jeff Dagle

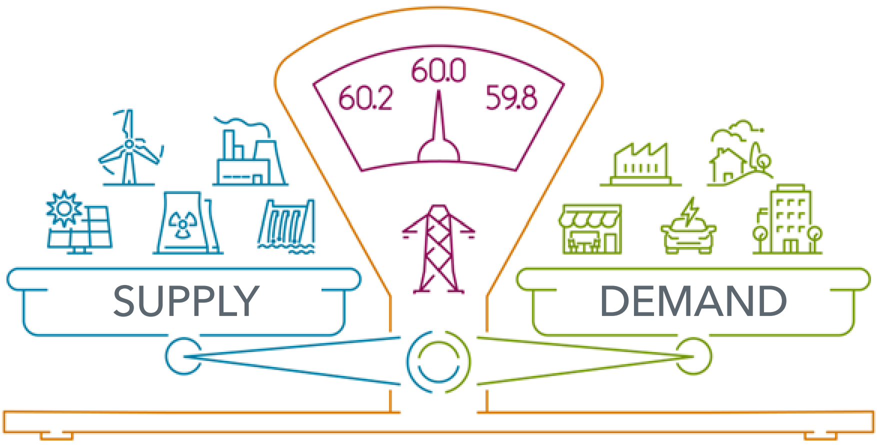
Control-centre applications

Normally, control centres utilize the prevailing local time zone. While UTC is sometimes used for automated data records, it is seldom used for human-to-human communications, unlike other real-time industries that span multiple time zones (e.g., air traffic control). Therefore, specifying the time zone is important when exchanging information between multiple organizations. Accurate time is necessary for logging events and coordinating actions. For applications that involve human operators, displays and other automation systems may be resolved to the nearest second of precision.

Generator dispatch

Changes, either in generation supply or customer demand, result in the system speeding up or slowing down, measured in tenths or hundredths of Hertz (Hz). Generation redispatch is a continuous process, and while accurately measuring frequency is necessary for the scheme to operate correctly, it does not require reference to time.

Balancing generation and load to maintain system frequency at all times – shown here for a 60 Hz grid



Source: PNNL

Sequence of events records

When a wide-scale disturbance (normally meaning a blackout) occurs, gathering event information requires sufficient precision to analyse the cascading failure sequence. Because automatic protection and control devices operate quickly, individual events must be resolved with millisecond precision to develop the sequence of events and conduct root cause analysis.

Furthermore, when an event transcends multiple organizations, investigators seek data synchronized to a common time reference. For example, the North American Electric Reliability Corporation (NERC) requires these records within ± 2ms from UTC.

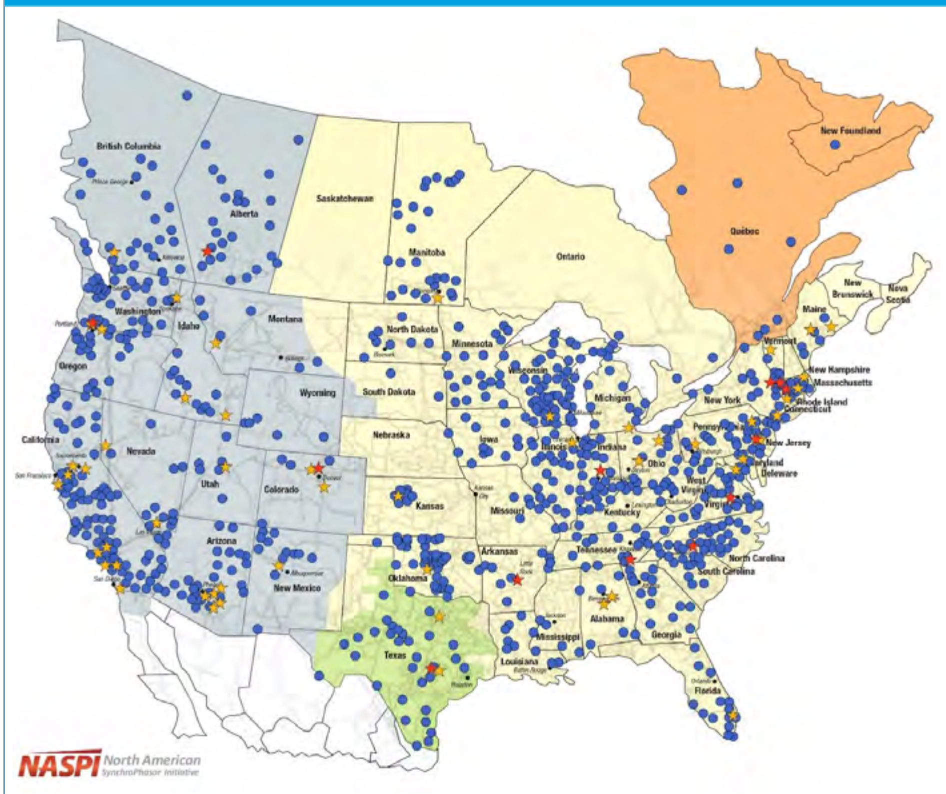
Advanced measurement systems

In recent decades, the inexpensive and ubiquitous precision time provided by Global Navigation Satellite Systems (GNSS) has enabled advanced measurement. Phasor measurement units (PMUs) that require a time synchronization source superior to a 10-microsecond (µs) precision, have been implemented worldwide, and since their measurements are shared between different organizations, UTC has been adopted as the timing reference.

More utilities are implementing advanced measurement systems for a variety of off-line and real-time applications. As these systems are deployed for increasingly critical applications, the accompanying requirements for more robust time synchronization increases in importance.

> *"Nearly every international engineering standard with time-synchronization requirements refers to UTC."*

Network-connected phasor measurement unit locations in North America



PMU locations

Transmission owner data concentrator

Regional data concentrator

With information available as of May 2017

Source: North American SynchroPhasor Initiative (NASPI) and PNNL

Advanced protection and control schemes

The International Electrotechnical Commission (IEC) has provided the emerging international standard for substation automation, IEC 61850, which may require as much as 1μs of precision for specific applications. Again, UTC is called out in this standard as a convenient reference.

Other advanced protection and control schemes rely on advanced time-synchronization methods. Examples of these include travelling-wave fault location and protection. Specifying UTC is most important when sharing data between organizations or when integrating multiple vendors' products into a common scheme.

The impact of leap seconds

The use of UTC as a time-synchronization reference goes well beyond the electric power industry. Nearly every international engineering standard with time-synchronization requirements refers to UTC. A common time reference is essential when exchanging data between multiple organizations or locations.

UTC is occasionally adjusted to maintain Earth's rotational synchronization. In some cases, PMUs have experienced leap-second disruptions during such adjustments, evidently due to inconsistencies in implementation between systems from different vendors or because of inadequate patching by end-users.

While implementing a leap-second rollover would seem like a straightforward process, issues are invariably discovered during the event that were not anticipated beforehand.

Leap seconds could be avoided altogether by switching to a different time reference, such as International Atomic Time (TAI). But given the wide acceptance and prevalence of UTC, there has been no impetus to make such a change.

Maintaining UTC as an international standard while introducing fewer leap-second adjustments could provide significant value to the electricity infrastructure sector going forward.

Perhaps switching to leap minutes – and hence adjusting our clocks about once a century rather than every couple of years – would be a reasonable long-term accommodation.

"Perhaps switching to leap minutes – and hence adjusting our clocks about once a century rather than every couple of years – would be a reasonable long-term accommodation."


Adobe Stock


Andreas Bauch


Karsten Buckwitz

UTC: Past, present and future

Andreas Bauch, Senior Scientist, PTB (national metrology institute) and Karsten Buckwitz, Senior Spectrum Advisor, BNetzA (Federal Networks Agency), Germany

Reliable access to accurate time has long been considered, and will remain indispensable for the proper functioning of modern infrastructure worldwide. Most users, industries, and organizations, as well as timing experts, agree on the need for a unique universal reference time scale and the General Conference on Weights and Measures (CGPM) decided in 1975, and reaffirmed in 2018, its recommendation to use Coordinated Universal Time (UTC) as the unique time scale for international reference and the basis for civil time.

UTC offers substantial advantages over other time scales:

- It is maintained by the International Bureau for Weights and Measures (BIPM), under the authority of the CGPM, with contributions from timing laboratories of many countries and hundreds of physicists and metrologists involved. This keeps it independent from the influence of any specific country, political power, or commercial entity.

- While UTC is widely recognized as the practical source of time and frequency in many countries, only a few specify UTC plus the appropriate offset as legal time. Germany is one such example, following UTC plus an offset of one or two hours, depending on the season, in accordance with the Law on Units and Time from 2008.

- UTC is disseminated through a real-time local approximation, or UTC(k), by the National Metrology Institute (NMI) or Designated Institute (DI) in each country. These institutes are entrusted domestically with the realization and dissemination of UTC(k) and in some cases of legal time. In Germany, the Federal Physical-Technical Institute (*Physikalisch-Technische Bundesanstalt* – PTB) disseminates legal time via the standard-frequency radio station DCF77 at 77.5 kilohertz (kHz), but also via the public telephone network and the Internet.

"Most users, industries, and organizations, as well as timing experts, agree on the need for a unique universal reference time scale."

Andreas Bauch and Karsten Buckwitz

ITU's role in time signal dissemination

The ITU Radiocommunication Sector (ITU–R) and its Working Party 7A play a vital role in providing the technical and regulatory basis for uninterrupted dissemination of timing signals worldwide. The definition of new time codes and the protection of standard frequency and time signal services remain important and ongoing tasks for Working Party 7A, with the support of concerned international organizations.

In decade-long discussions among all involved parties, consensus has been reached that alternative time scales should not be utilized as timing sources. Instead, the practice of realizing UTC should be adapted to the needs of the 21st Century.

"The practice of realizing UTC should be adapted to the needs of the 21st Century."

Previous World Radiocommunication Conferences conducted trials on updating UTC, and the 2015 conference (WRC-15) considered the feasibility of achieving a continuous reference time scale, whether by modification of UTC or some other method. This WRC-15 discussion took place in accordance with a decision in the previous cycle through Resolution 653 (WRC-12).

Under the subsequent Resolution 655 (WRC-15), the Director of the ITU Radiocommunication Bureau will report to the upcoming WRC-23 on the outcomes of activities related to the various aspects of current and potential future reference time scales, as well as on the content and structure of time signals to be disseminated by radiocommunication systems.

Germany's perspective

Several countries have supported Working Party 7A in preparing for the WRC-23 discussion, like Germany, with a preparatory team working intensively on the topic between 2015 and 2022. Germany welcomed the final report, "Content and structure of time signals to be disseminated by radiocommunication systems and various aspects of current and potential future reference time scales, including their impacts and applications in radiocommunication" (ITU–R TF.2511), together with the associated note to the Director of the ITU Radiocommunication Bureau.

Germany fully supports the report's conclusions and suggestions, which are likely to form the basis of the Bureau Director's report to WRC-23.

Updating ITU's time-scale resolution

Many administrations, including Germany, have called for revising Resolution 655 (WRC-15), "Definition of time scale and dissemination of time signals via radiocommunication systems". This is essential to finalize the process and adapt UTC for the future.

Notable key findings and lessons have emerged through discussions on the topic since 2012:

- BIPM is responsible for the definition and publication of the reference time scale UTC in accordance with Resolution 2 of the 26th CGPM, held in 2018;
- CGPM will determine the timeline and a future limit on the quantity UT1-UTC, as laid down in Resolution 4 of the 27th CGPM in 2022; and
- the task of defining the properties of UTC is not part of spectrum regulation within ITU–R.

Continuing the dialogue, open to all

Interested users, industries and organizations – and also, of course, timing experts – are invited to join the vital and necessary dialogue on these issues in Working Party 7A. This ongoing discussion is taking place in accordance with the Memorandum of Understanding between ITU and BIPM, but also on the expected update of Resolution 655 at WRC-23.

"Interested users, industries and organizations – and also, of course, timing experts – are invited to join the vital and necessary dialogue on these issues in Working Party 7A."

Timekeeping and the need for astronomical conformity

Rev. Paul Gabor, Vice Director, Vatican Observatory, US

Plato's *Timaeus*, in sections 37d and 38b-d, presents time as the annual and diurnal motion of celestial bodies: "a moving image of eternity." Innumerable classical texts from around the world agree that astronomical cycles are the symbolic foundation of time itself as perceived and lived by human societies.

Calendars are a practical reflection of this principle. Their history manifests the universal desire for timekeeping schemes that symbolically link human lives with cosmic cycles, the civil day symbolically linked to the solar day.

Symbols are rooted in the "collective unconscious" (to use a Jungian term). Let us, therefore, briefly peek under the surface and examine what changes to timekeeping might do to a society's symbolic underpinnings.

> *Astronomical cycles are the symbolic foundation of time as perceived and lived by human societies.*
>
> Rev. Paul Gabor

Public understanding of science

The 1985 report on the Public Understanding of Science (Royal Society, UK, also known as the "Bodmer Report") noted a disconnect between the general public and the sciences. To address this, it encouraged programmes in science communication and education, along with public engagement.

If anything, however, the last 28 years have witnessed increasing, and ever deeper, anti-science sentiments.

The idea that education alone will bring about societal change stems from reductionist anthropology, typical of the 18th Century Enlightenment. The attitude, "Once people understand the rational reasons, they will be compelled to accept the expert point of view," implies that the only avenue open to rational minds is to agree with technical and pragmatic arguments. There are many non-technical dimensions of our lives, and the assumption is that they can all be discussed rationally.

At the same time, sharing symbols is one of the crucial bonds holding any human society together. If "we" feel "they" belittle "our" symbols, strife follows.

As scientists, we must question everything. Unfortunately, this has prompted growing numbers of people to feel that experts and other figures of authority have been trampling precious traditions underfoot.

The public debate surrounding the COVID-19 pandemic has shown how many people are leery of expert advice. One of the reasons could be social alienation, with people feeling left out of the decision process, outsiders in their own world, battered by wave upon wave of rapid, incessant, and incomprehensible change.

The sensitivity of unifying standards

Unifying the standards followed in any set of systems and technologies is rational and practical. From another viewpoint, however, imposing uniformity is a symbolic gesture linked to power, conquest and domination.

That is why we must be doubly careful in this area. Insensitive change can be seen as disrespect, and unifying standards may be viewed as conquest.

"Calendars serve as a link between mankind and the cosmos."

— L. E. Doggett, "Calendars"

(in P. K. Seidelmann, ed., Explanatory Supplement to the Astronomical Almanac. University Science Books, 1992, pp. 575–608.)

"As scientists, we must question everything."

The reassurance of astronomical conformity

The principle of astronomical conformity is crucial in civil timekeeping for reasons that go far beyond the purely practical. Although timekeeping schemes like the seven-day week can enjoy the mysterious air of mythical timelessness, their history demonstrates a surprising level of flexibility – *provided the underlying symbolism is maintained*.

Symbolism depends upon general perception and is somewhat vague in its relationship to exact facts. Thus, as long as we collectively perceive civil time as a reflection of astronomical phenomena, the symbolism can be maintained.

Resolution 4 of the last General Conference on Weights and Measures (CGPM 2022) allows us to do just that. It does not suggest decoupling civil timekeeping from Earth's rotation once and for all. On the contrary, Resolution 4 presents a temporary compromise, including a process to safeguard the astronomical conformity of civil timekeeping schemes in the long run.

As long as we have described the measure as temporary and refrained from "abolishing" or "suppressing" or "discontinuing" the leap second, we have prevented this particular matter from adding to public unease and alienation.

After all, nobody can presume to have an "ultimate" solution. Furthermore, as the history of timekeeping teaches us, departures from overall astronomical conformity do not last.

The existing compromise

Overall, the 1972 leap-second mechanism that underlies the definition of Coordinated Universal Time (UTC) continues to represent a good compromise between the practicality of a continuous time scale and the symbolism of astronomical conformity. It has been in place for half a century and, although it does require some effort among various groups of time users, those 50 years of practice have demonstrated that we can deal with occasional one-second discontinuities.

"50 years of practice have demonstrated that we can deal with occasional one-second discontinuities."

Adobe Stock

Countdown to WRC-23

Member States of the International Telecommunication Union (ITU) will convene in Dubai, United Arab Emirates, from 20 November to 15 December 2023 for the next World Radiocommunication Conference (WRC-23).

The outcomes will be pivotal in shaping future technical and regulatory frameworks for radiocommunication services all over the world.

The conference is the opportunity for ITU Member States to update the Radio Regulations – the international treaty that governs the use of the frequency spectrum and associated satellite orbits. The ITU Radio Regulations enable countries to provide access to new technologies and services – such as wireless terrestrial and satellite systems – while simultaneously safeguarding existing services, ensuring that all radio systems can coexist without harmful interference.

ITUWRC DUBAI2023

The digital revolution has opened the doors to a variety of new applications, which are spurring greater demand for the world's limited radio spectrum. In the case of space services, growing numbers of users are also interested in limited orbital resources.

In some cases, demand growth necessitates changes to the regulatory framework.

Always adapting and advancing

The Radio Regulations (dating back to 1906) have continually taken advantage of technological advances to make spectrum use more efficient and facilitate spectrum access.

Modifications to the treaty have always:

- addressed the needs of **new and existing services**.
- ensured **timely availability** of spectrum, as well as corresponding regulatory provisions.
- maintained the benefits of **globally harmonized frequency bands**.

Setting the stage

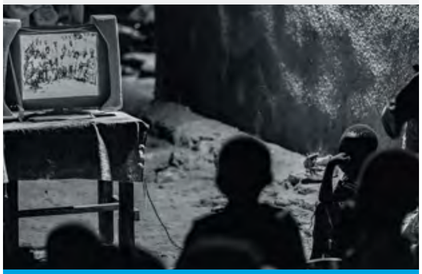
At the upcoming conference, ITU's global membership aims to find solutions for the introduction of new technologies, provide a stable regulatory framework for satellite networks, facilitate the modernization of radiocommunication systems worldwide, and protect existing services.

The output of the final preparatory meeting (CPM23-2) in Geneva, Switzerland, between 27 March and 6 April will set the stage for those crucial decisions at WRC-23.

The draft Conference Preparatory Meeting Report includes important study results from the ITU Radiocommunication Sector (ITU–R) ahead of WRC-23, as well as proposed ways forward to resolve issues on the conference agenda.

WRC-23: International regulation of satellite services | Read more

Why WRC-23 will be pivotal for terrestrial services | Read more



WRC-23: Safeguarding high-quality broadcasting services | Read more

WRC-23: Technical preparations for science services | Read more

Consolidated spectrum proposals

Regional preparations are a key element in the success of the quadrennial ITU gathering to update the Radio Regulations.

The ITU Radiocommunication Bureau, in accordance with Resolution 72 (Rev. WRC-19), supports regional preparations and inter-regional consensus-building by organizing three ITU inter-regional workshops during the four-year study cycle between World Radiocommunication Conferences.

Six main regional telecommunication organizations (RTOs) support discussions and consensus-building among governments, regulators, and telecommunication service and equipment providers across six regions spanning the globe.

ITU has held two Inter-regional Workshops on WRC-23 Preparation, in late 2021 and late 2022. The third Inter-Regional Workshop in the run-up to WRC-23 is intended to address some of the most complex issues expected at the conference.

ITU News Magazine: Countdown to WRC-23

Download your copy

Regional telecom organizations highlight key topics for discussion at WRC-23

Arab States, ASMG
Read more

Africa, ATU
Read more

Europe, CEPT
Read more

Commonwealth of Independent States, RCC | Read more

Americas, CITEL
Read more

Asia and the Pacific, APT
Read more

Stay current //
// Stay informed

// Global technology trends // Views from thought leaders //
// ITU insights and initiatives //

Follow us to receive:

ITU Newsletter
//
Regular round-up
//

News blog
//
Latest angles
//

ITU News Magazine
//
In-depth stories
//

ITU Podcasts
//
Timely interviews
//

Press releases and media advisories
//
Key updates
//