Consultative Committee for Time and Frequency (CCTF)

President: Mr Luc Erard Executive Secretary: Dr Patrizia Tavella

1. Executive summary

The CCTF has actively supported research and coordination activities in the development of primary and secondary frequency standards, time and frequency comparison techniques, as well as algorithm development. Particular effort has been dedicated to the development and evaluation of secondary frequency standards, based on optical transitions. The CCTF has coordinated one key comparison, CCTF-K001.UTC, based on the realization of the international reference time scale UTC. The CCTF has strong liaisons with scientific and industrial communities to promote the mutual benefits in the use of a unique reference time scale and accurate development of time and frequency metrology.

2. Scope of the CC

The CCTF is concerned with the definition and realization of the SI second; the construction of a stable and accurate reference time scale ensuring access to the SI second and realizing of a time coordinate for the dating of events. The Committee promotes and supports research in all related fields through nine working groups and supports global comparability and traceability to the international reference UTC (coordinated universal time), which is realized at the BIPM.

The CCTF liaises with international organizations that have different interests in time and frequency metrology, covering a wide range of applications such as the operation of global satellite navigation, time tagging, geodesy, astronomy and telecommunications.

3. Strategy

The CCTF strategy document was prepared by the CCTF Working Group on Strategic Planning (CCTF-WGSP), under the leadership of the President of the CCTF. The document is available at https://www.bipm.org/utils/en/pdf/CCTF-strategy-document.pdf.

The CCTF strategy follows the three objectives indicated by Decision CIPM/106-16:

- to progress the state-of-the art by providing a global forum for NMIs to exchange information about the state of the art and best practices,
- to define new possibilities for metrology to have impact on global measurement challenges by facilitating dialogue between the NMIs and new and established stakeholders, and
- to demonstrate and improve the global comparability of measurements. Particularly by working with the RMOs in the context of the CIPM MRA to:
    - plan, execute and monitor KCs, and to
    - support the process of CMC review.

The Committee identified a variety of stakeholders including: NMIs and other institutes that realize the unit locally and maintain a time scale; international bodies representing user communities; service providers; science services; and regulators. Effective communication with the stakeholders is a strong point of the CCTF strategy, since they provide feedback to the Committee and impact the work of the BIPM.

The strategy document highlights core activities in the mid and long term:

- Studies on time scales for different applications; supporting new applications for highly accurate time and, to take advantage of developments in dissemination methods, to continue to develop more rapid predictions of UTC;
- Incorporate new time transfer and time dissemination methods in terms of increased accuracy, reduced cost, easier accessibility and the ability to coexist with other users of the infrastructure;
- Very accurate primary standards will start challenging the best available time and frequency transfer techniques, it will be important to develop a range of portable and highly accurate primary standards that will confirm the performance of new, innovative long-distance clock comparison modes;
- Developing algorithms for time and frequency measures with the consequent effort in disseminating their precise use and understanding;
- Promoting evaluations of the comparative stability, uncertainty and reproducibility of optical clocks based on the same ion and atom species, in preparation for a future redefinition of the second;
- Encouraging the BIPM to develop multi-technique time transfer and to implement rapid-UTC solutions;
- Monitoring the evolution of Global Navigation Satellite Systems (GNSS) and their internal system times.

4. Activities and achievements since the last meeting of the CGPM

Since the 25th meeting of the CGPM, the CCTF has met twice in September 2015 and June 2017. The meeting in 2017 was exceptionally held after only two years with the aim of proposing a resolution to the 26th meeting of the CGPM (2018) on the definition of time scales. Despite official requests, a formal definition has never been given by the CGPM on this matter. All of the CCTF Working Groups held regular meetings.

Main activities carried out cover:

- *Realization and operation of Primary and Secondary standards:*

  New Cs fountains as well as new optical frequency standards realizing secondary representations of the second have been developed by NMIs and, through the coordination of the CCTF Working Group on Primary and Secondary Frequency Standards (CCTF-WGPSFS), their results have been reported to the BIPM for the steering of International Atomic Time (TAI). In 2017 data were reported to the BIPM from six Cs fountains, two Cs beam standards continuously operating as clocks, and three secondary standards based on Rb and Sr atoms.

  In 2018 the measurements from one additional Cs fountain and a new secondary standard based on the Sr atom were also reported.

- *Optical clocks and recommended frequencies:*

  Different optical atomic transitions are currently being studied and high-precision measurement experiments are ongoing, based on diverse atom and ion species showing the capability to reach 10^{-18} accuracy. The CCL-CCTF Frequency Standards Working Group produced an updated list of recommended frequencies in 2017 as secondary representations of the second; see https://www.bipm.org/en/publications/mises-en-pratique/standard-frequencies.html

- *Development of optical fibre and other advanced links for time and frequency transfer:*

  Optical links (temporary and permanent) started operating between time laboratories for testing their capabilities for very accurate frequency and time comparisons. In particular, rapid developments occurred in European laboratories with the support of EURAMET, but the network of optical links is developing in different parts of the world. The BIPM is evaluating the possibility of using this technique in the computation of UTC, as well as setting up a fibre connection to the European network with the aim of validating the GNSS calibrated links.

  The Two Way Satellite Time and Frequency Transfer technique has been enhanced by a new development based on a Software Defined Radio Receiver, which is currently under development and testing in several time laboratories. The results obtained so far in the receiving chain are quite encouraging and the TWSTFT Working Group has created a Task Force for further collaborative development and testing of the technique.

- *Improvement and calibration of GNSS time transfer:*

  The availability of new GNSS systems, such as the European Galileo and the Chinese Beidou, represent a possibility for multi-constellation time transfer to be used by NMIs and the BIPM for clock comparison and the computation of UTC. Tests are ongoing in different laboratories.

  Many NMIs are also directly collaborating with GNSS providers to support their timing systems and the synchronization to UTC.

  Cooperation between the BIPM and the RMOs was formalized to maintain the regular calibration of GNSS equipment used in UTC computation with the aim of reducing the world-wide time transfer uncertainty to 2-3 ns. Guidelines for GNSS equipment calibration have been prepared by the BIPM Time Department and distributed to the RMOs. Calibration campaigns under this new organization are ongoing.

- *Improvement of the UTC and rapid UTC algorithms*:

  Continuous improvements are evaluated and tested at the BIPM on the algorithms that treat laboratory clock data to calculate UTC and rapid UTC (UTCr). The UTCr algorithm was modified in 2017 to maintain a closer agreement with respect to UTC. Since then, the difference has remained below 2 ns. UTCr weekly solutions have been published regularly since June 2013.

  A main effort was dedicated to the evaluation of uncertainty of the differences UTC-UTC(*k*) taking into account correlations and biases due to the absence of calibration.

- *Promoting the use of UTC as unique reference time scale*:

  The CCTF and the BIPM contributed actively to the discussion on the possible modification of the definition of UTC. The BIPM and several NMIs support the activity of the International Telecommunication Union (ITU-R) WP 7A, including participation at the 2015 World Radiocommunication Conference, and working together for a common understanding of the benefit of a single reference time scale.

  The BIPM and NMIs are also involved in the International GNSS Committee of the

United Nations aiming to harmonize the different navigation and timing systems.

4.1. Challenges and difficulties

Having the evidence for an achievable accuracy of 10^{-18} for the next generation of frequency standards, it is becoming urgent and critical to develop time and frequency transfer with similar performance. Optical fibres are promising but they have intrinsic difficulties in establishing intercontinental links, and several complex and expensive processes have to be followed to obtain long-lasting contracts from optical fibre providers.

A number of new time laboratories are being set up, particularly in developing countries and economies. Their main aim is to disseminate time and frequency and to support calibration needs in the country. There is an emerging need for education and capacity building in these laboratories to assist with the development and the correct implementation of time and frequency metrology.

There is a need for time scales in many applications that are different from timekeeping, for example GNSS or telecommunication systems. It is difficult to limit the proliferation of new time scales, which together with the already existing TAI, UTC, and UTCr, run the risk of causing confusion, particularly when they differ from an integer number of seconds.

5. Outlook in the short and long term

The main areas of research over the next few years are expected to be:

- Development of optical frequency standards and their applications, including inclusion in UTC, yielding a possible redefinition of the second.
- Testing and development of new or improved time and frequency transfer techniques that are able to disseminate the quality of optical frequency standards over distances.
- Improvement of the quality and availability of the international reference UTC and its national real-time approximation realized by NMIs to support the world-wide adoption and recognition of a single reference time scale.
- Working in collaboration with other scientific and industrial communities to identify their needs concerning time and frequency measures and being able to address the challenges with mutual benefits.

Annex: CC Data

CCTF set up as CCDS in 1956
Renamed CCTF in 1997

President: L. Erard

Executive secretary: P. Tavella

Membership: 25 members, five liaisons, four observers

List of CCTF members and observers: http://www.bipm.org/en/committees/cc/cctf/members-cc.html

Meetings since the 25th CGPM meeting: 17-18 September 2015, 8-9 June 2017 ;

Full reports of the CCTF meetings: https://www.bipm.org/utils/common/pdf/CC/CCTF/CCTF20.pdf https://www.bipm.org/utils/common/pdf/CC/CCTF/CCTF21.pdf

Nine CCTF Working Groups:: https://www.bipm.org/en/committees/cc/cctf/

- Time Scale Algorithms (WG-ALGO)
- Coordination of the Development of Advanced Time and Frequency Transfer Techniques (WGATFT)
- GNSS Time Transfer (WGGNSS)
- CIPM MRA (WGMRA)
- Primary and Secondary Frequency Standards (PSFS)
- Strategic Planning (WGSP)
- International Atomic Time TAI (WGTAI)
- Two-way Satellite Time and Frequency Transfer (WGTWSTFT)
- CCL-CCTF Frequency Standards (WGFS)

CCTF Comparison activity	Completed	In progress	Planned [period]
CCTF key comparisons (and supplementary comparisons)	1, monthly	Ongoing (+1)	ongoing
BIPM comparisons	0	0	0
CC pilot studies	0	0	0
CMCs	776 CMCs in 19 service categories registered in the KCDB		