ITU-R SPECIAL RAPPORTEUR GROUP ON THE FUTURE OF THE UTC TIME SCALE

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Abstract

As a result of issues raised by sector members of the ITU-R (International Telecommunication Union - Radiocommunications) and a letter from the Director of the Bureau International des Poids et Mesures (BIPM) to the Secretary General of the ITU, a new question, ITU-R 236/7 (2000) "The Future of the UTC Timescale," was generated by ITU-R Study Group 7 (Science Services) Working Party 7A (Standard Frequency and Time Signal Services). The question considers the definition and future use of Coordinated Universal Time (UTC) in the ITU-R Recommendations. A major change to the UTC timescale as defined in the current recommendations could have a potentially significant impact on broadcast time and frequency services, synchronization of communications networks, navigation systems, and time distribution performance. Accordingly, Study Group 7, Working Party 7A has established a Special Rapporteur Group (SRG) to specifically address the question of the future of the UTC timescale, the associated leap second, and related issues. The SRG has held coordination and technical exchange meetings to gather pertinent data and discuss alternative approaches to the issues. The result of these efforts had not produced sufficient information for analysis of alternatives nor produced a clearly defined course of action. However, the SRG wanted to present results and discuss viable alternatives with representative parties that had come forth as a result of these activities. For that purpose, the SRG organized a Special Colloquium for deliberating and reporting on these issues to the ITU-R.

THE UTC TIME SCALE

UTC is defined by in the International Telecommunication Union - Radiocommunications (ITU-R) recommendations as the basis for standard frequency and time signal emissions. These standard frequencies and time signals are the foundation of frequency generation and regulating broadcasting for all forms of telecommunications **[1]**. UTC is determined and maintained by the Bureau International des Poids et Mesures (BIPM), with assistance from the International Earth Rotation Service (IERS). It represents a combination of Universal Time (UT), the time scale based on the rotation of the Earth corrected for polar motion, which is designated UT1, and International Atomic time (TAI), which is determined by atomic clocks and primary reference standards operated by timing centers and laboratories around the world. UT1 is actually a measure of the Earth's rotation and orientation in inertial space. This measure is necessary for determining position on the Earth by celestial navigation techniques. However, due to irregularities in the Earth's rotation, UT1 is not uniform. TAI is a practical realization of a uniform time scale from which all other uniform time scales are derived.

UTC corresponds exactly in rate with TAI, but is kept within 0.9 second of UT1 by the occasional insertion or deletion of 1-second steps, called leap seconds. The necessity of inserting a leap second is determined by the IERS. Since 1972, when UTC was introduced, there have been 22 leap seconds, all of which have been positive. The 0.9-second tolerance between UT1 and UTC by leap seconds was augmented by providing an additional parameter known as DUT1 so that the result was a real-time estimate of UT1 accurate to 0.1 seconds for celestial navigation. However, the motivation for the leap second to support navigation needs is complicating operation of today's satellite navigation and communication systems. These systems are being disrupted and complicated in maintaining their precise timekeeping systems that must periodically accommodate leap second adjustments.

ISSUES AND ACTIONS

ITU-R sector members raised issues over the discontinuous nature of UTC and resultant problems that occurred. A letter from the Director of the BIPM to the Secretary General of the ITU **[2]** emphasized the issues and the ITU's responsibility for UTC. Consequently, a new question was generated by ITU-R Study Group 7, Working Party 7A calling for studies and consideration of the definition and use of UTC. A letter was sent from the ITU-R to all sector members **[3]** advising them of the new question, the formation of a Special Rapporteur Group to address the question and inviting participation in the SRG. A major change to the UTC timescale as defined in the current recommendations could have a significant impact on synchronization of communications networks, navigation systems, and time distribution performance.

The SRG has held coordination and technical exchange meetings to gather data, analyze the issues, and discuss alternatives to reduction or elimination of the operational impact of the leap second. Participants or observers from the International Astronomical Union, the International Union of Radio Science, the International union of Geodesy and Geophysics, the Consultative Committee for Time and Frequency, and the BIPM have participated and contributed to the investigations. Specific meetings were held in conjunction with the Precise Time and time interval Planning Meetings, the European frequency and Time Forum, and at the BIPM. The results of these meetings and other efforts had not produced a body of empirical data and analysis compelling a technical solution. Consequently, the SRG organized a special colloquium for deliberating and discussing the issues with representative parties from participating organizations and others that had come forward as a result of meetings and publications requesting data.

COLLOQUIUM ON THE UTC TIMESCALE

The Istituto Elettrotecnico Nazionale (IEN) in Torino, Italy, hosted the colloquium. This was particularly significant, since leading scientists from the IEN had played a significant role in the original formulation of UTC. Two days were devoted to presentations and discussions. The venue of the Colloquium included separate sessions in the areas of International Timekeeping, Navigation, Earth Rotation, Telecommunications, and Internet Timing. These areas were chosen as representative of the major areas that would be impacted by changes in the UTC Timescale. Introducing each session were invited presentations by distinguished experts. Contributed presentations were solicited to offer the opportunity for additional viewpoints to be expressed. At the conclusion of the Colloquium, a general session summarized the results of the Colloquium, and then SRG members held an executive session.

TECHNICAL PROGRAM OVERVIEW

The main points of the technical program covering the origins and definitions of UT1 were presented, the resultant form being proportional to the Earth rotation angle around a moving rotation axis and remaining approximately in phase with Greenwich solar time. Attempts to definite a uniform time reference ranged from the use of paleontological data up to modern efforts using Atomic Time. The early history of UTC involves the use of steering UTC to maintain a small value of DUT1 by using frequency offsets in the period prior to 1972. The evolution of time steps for UTC developed into a more stable and manageable system.

UTC then became a key element of International Timekeeping. Leap Seconds were determined and procedures for introduction worked well. However, the systems that use time and the capability for maintain precise time worldwide evolved such that it is becoming increasingly inconvenient to manage leap seconds. Complicating the process of managing UTC has been the proliferation of unique time scales to meet the needs of different applications. Discussion of satellite navigation systems emphasized this point in that the time offset between different satellite clocks must be small and continuous. This synchronization of the satellite clocks provides the basis for measuring the signal propagation time, and hence the range, from multiple satellites, accurately and simultaneously. Synchronization to a standard reference time is not necessary for the system to be an effective navigation system. What is necessary is that all the clocks in the system be precisely synchronized. Satellite navigation system time has been referenced to an external reference time standard for the purposes of using the satellite navigation system as a means of transferring time from the reference to another external clock or timing system. Even without an external time reference, satellite navigation system time could be used effectively as a time standard because of its precision and universal availability. This utility of the satellite navigation systems could lead to a proliferation of time standards and time scales.

The problem of the proliferation of different time scales is evidenced by the GPS navigation system having GPS Time as its basis, Galileo having TAI, and GLONASS having UTC. Because the designers of systems using these navigation aids may not be totally familiar with the fundamental concepts of modern timekeeping, there is danger of an error or confusion causing a catastrophe, either in the air or on the ground resulting from using different time scales or reference times. It is essential that the time of an aircraft's position be correctly identified and recorded. Air traffic controllers, using UTC, must insure that the time being used by an aircraft's navigation system to record its position be the same. The difference between UTC and GPS Time is 13 seconds and that between UTC and TAI is 32 seconds.

The use of UTC as an approximation of UT1 was apparent in the presentations and discussions on the calculation of satellite orbits. Because UTC is kept within a second of UT1, many computer programs have been programmed to utilize this fact in initializing the determination of approximate orbits of spacecraft. These approximate orbits are applied to such tasks as pointing high gain antennas and initializing more precise orbit determination programs. Considerable discussion was conducted on this application and confusion over the costs and impact of potentially reprogramming these systems.

The Director of the IERS presented a brief discussion on the causes for variations in the Length of the Day (LOD). The current IERS products were described, including the statistics of their current prediction capabilities. The IERS can currently predict UT1 with an accuracy of about 300 ms out to 3 years. Using a simple model including a seasonal term, a bias, and a drift, it is possible to produce an prediction of UT1 accurate to about 1 second over 4 years. Such a capability would enable an table of corrections to be determined well in advance so that a user could use a table look up technique to correct UTC to UT1, rather than relying on the broadcast of DUT1.

It was also apparent that UTC as presently defined is not sustainable into the future. The deceleration of the Earth's rotation is projected to increase to the point that multiple leap seconds per year may be required to maintain the DUT1 tolerance. The trend in the characteristics of modern telecommunications systems and advances in other systems requires a continuous uniform time scale for their operation. The projection was that in the future there would be a greater need for continuity and increased precision. The telecommunication representatives recommended the continuation of UTC without leap seconds. Computer networks also have significant problems with leap seconds. Computer protocols cannot represent an additional second within a minute, i.e., reading 60 seconds prior to rollover to 0 seconds in the next minute. These systems effectively stop when this occurs. Furthermore, because leap seconds can occur in the middle of a working day for portions of the world, electronic commerce and digital financial transactions could be seriously affected.

The paper dealing with computer protocols and application software recognized the problem of computers in dealing with leap seconds. As a possible fix to the problem, it was suggested that either the leap second be ignored or the duration of the second within the computer be modified or varied over the leap second interval. This approach effectively varies the frequency of the internal clock rate (frequency) and, consequently, the continuity of the time intervals. This approach is similar to the frequency offset approach experimented with at the onset of UTC that was found quite undesirable.

IERS Leap Second Survey

The IERS conducted a survey by means of their Web site in the spring of 2002. There were 243 responses - 21% from astronomers, 16% from the timing community, 15% from navigators, and 13% from geodesists. The remaining 35% consisted of space scientists, others in the timing community, the telecommunications industry, and geophysicists. 88% of those who responded indicated that they were satisfied with the current UTC determination method. However, there was some uncertainty in whether the responders were representative of the technical areas and regular subscribers to IERS publications. Consequently, assessing the results of the survey was difficult.

Summary of Roundtable Discussion

In summarizing during the roundtable, it became apparent that the discussion was actually about three primary applications of the time scale. These three applications represented different prospective levels of service: high-accuracy continuous service, medium- to high-accuracy with possible interruptions, and low- accuracy phased with solar time (approximately UT1). The highest level of service is not available at present. TAI would most readily satisfy that condition, but it is not generally available or actually realized physically. So to achieve continuous capability by using TAI would require some method of stepping UTC to TAI, or restarting systems on a new time scale. This discussion lead into a review of four prior suggestions that had been put forward, which were: 1) Abandon leap seconds, 2) Use TAI instead of UTC, 3) Change leap second name and its representation, and 4) Move the leap second epoch to 1 January solely. In any case, the need for an independent means of widespread dissemination of UT1 data became apparent, and the IERS representatives accepted their responsibility for this need.

Most users with real time requirements for UT1 came from the astronomical community and those who needed low-precision values of UT1 for non-precision orbits of Earth-orbiting objects. Dennis McCarthy proposed that, in the future, these users be urged to use the more accurate difference values of UT1-UTC as published by the IERS and not to assume that UTC = UT1. While there was a proposal to have a low-precision UT1 and a high-precision TAI transmitted, it was pointed out that this could be considered a step backward to the time when there was both ET and UT. One additional point was raised concerning UT1: UT1 is really related to Earth orientation and is not a true time scale. Therefore, the ITU-R should not be concerned with transmitting it. Time should be decoupled from the rotation of the Earth.

The inability of computers to be able to handle leap seconds lead to the proposal to hide the leap second by changing the length of the second via special subroutines within the computer. There was strong opposition to such a proposal, because it introduced a non-SI frequency for that second and possibly more. The proposal to introduce a leap hour in place of the leap second led to comments in opposition because it would necessitate a change in time and frequency standard transmission that could not be currently handled. Consequently, it was put forward that if the leap second is not abandoned, then the current system should remain in place.

The overall results of this discussion were:

1. There was no overwhelming consensus on maintaining the status quo or pursuing an alternative.
2. There was some agreement on the general characteristics of a potential alternative that emerged (see below).
3. This alternate proposal should be passed on to WP7A for development of an opinion to be transmitted to the appropriate international organizations.
4. Advances in technology in communications, navigation, and other fields would be enhanced in their interoperability by the adoption of a single, internationally recognized time scale for use in civil, engineering, and scientific applications.

POTENTIAL ALTERNATIVE TO THE LEAP SECOND

The results of the roundtable discussion lead to defining the following characteristics of the future of the UTC time scale.

1. Any change should slowly evolve from the current UTC Standard by transition to a uniform timescale, perhaps to be called *Temps International* (TI) to distinguish the new time scale from former ones.
2. A suggested date for inaugurating any change would be 2022, the 50th anniversary of the UTC timescale. The date suggested was influenced by the lifetimes of existing systems that would be expensive to change.
3. The new scale, TI, should be a continuous atomic time scale without leap seconds synchronized with UTC at the time of transition.
4. Responsibility for independently disseminating UT1 information should be that of the IERS.

These results were reported to the ITU-R Working Party 7A for consideration.

REFERENCES

[1] ITU-R Recommendation TF.460-5 in **ITU-R Recommendations: Time Signals and Frequency Standard Emissions, Volume 2000, TF Series,** 2001 (International Telecommunication Union, Radiocommunication Bureau, Place des Nations, CH-1211 Geneva 20, Switzerland).

[2] Letter from Director of Bureau International des Poids et Mesures (T. J. Quinn) to the Secretary General of the ITU, 10 June 1999.

[3] Letter from Director of the Radiocommunication Bureau of the ITU (R. W. Jones), 8 January 2001.

[4] ITU-R Question TF.236/7, *"The Future of the UTC Time Scale,"* in **Addendum to ITU-R Recommendations: Time Signals and Frequency Standard Emissions, Volume 2000, TF Series,** 2001 (International Telecommunication Union, Radiocommunication Bureau, Place des Nations, CH-1211 Geneva 20, Switzerland).

QUESTIONS AND ANSWERS

MARC WEISS (National Institute of Standards and Technology): I was sorry to hear that changing the definition of TAI was so problematic. My crystal ball tells me that sometime in about 20 years or so, we may be changing the definition of the second anyway. Maybe an idea would be to change it so that it is closer to the Earth rate, and do that every hundred years or so. Have you people talked about that?

RON BEARD: Well, as I said, every time I had suggested that we change the definition of the second, I thought I was going to be taken outside and lynched. But I think that is a possibility and something could be looked at in a transition plan to a possible redefinition or a study for a redefinition that might change that in the long term. I do not think that is anything that we could positively recommend today.

WEISS: But with the way we have cold cesium fountains, and now people are looking at optical frequencies that may use other transitions, we may redefine the second. We are talking hundreds of years here.

BEARD: Redefinition of the second is really an ITU issue. That would be more of a BIPM issue or CPM issue. It is not something that we can really base an action on.

DENNIS McCARTHY (U.S. Naval Observatory): In response to your suggestion, Marc, the reason for that is that all the physical standards would have to be redefined, such as length, etc. They felt that this was such a problem that it wasn't a viable solution at this point. I agree, that is the most fundamental solution to the problem, but it has great significance in other areas.