UTCr: a rapid realization of UTC

Note: This paper has been sent for publication (EFTF2012), and presents the results of the UTCr Pilot Experiment in May 2012. An updated report will be presented at the CCTF.

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***Abstract*— Considering the evolving needs of time metrology and the convenience of allowing the contributing laboratories access to a realization UTC more frequently than through the monthly *Circular T*, the BIPM Time Department has started to implement the computation of UTCr, a rapid realization of UTC published every week and based on daily clock and time transfer data. Results of the first weeks of a pilot experimentation of this new product are presented.**

I. Introduction

At present the Coordinated Universal Time UTC is calculated with one-month data batches, and is available monthly in the BIPM *Circular T* [1] under the form of [*UTC*-*UTC*(*k*)], where *UTC*(*k*) is a local realization of UTC by participating laboratory k, at five-day intervals. Extrapolation of values over 10 to 45 days based on prediction models is necessary to many applications. UTC, as published today, is not adapted for real and quasi-real time applications. A more rapid realization would benefit e.g. to the following:

- UTC contributing laboratories would have more frequent assessing of the *UTC*(*k*) steering, and consequently better stability and accuracy of *UTC*(*k*) and enhanced traceability to UTC;
- Users of *UTC*(*k*) would access to a better "local" reference, and indirectly, better traceability to the UTC "global" reference;
- Users of Global Navigation Satellite Systems would get a better synchronization of GNSS times to UTC, through improved UTC and *UTC*(*k*) predictions: this is the case of UTC(USNO) for GPS, UTC(SU) for GLONASS, and of the UTC(k) to be used in the generation of Galileo, BeiDou and Gagan system times.

For these reasons, the BIPM has proposed to provide UTCr, a new realization of UTC available with a reduced delay. The paper presents the algorithm used and the main characteristics of UTCr in Section II, then reports in Section III on its implementation in a Pilot experiment initiated in January 2012. Comparisons of UTCr with the final UTC for the first months of 2012 are discussed in Section IV.

II. Characteristics and Realization of UTCr

A. *Main characteristics of UTCr*

UTCr is based on daily data reported daily by contributing laboratories. The solution is calculated every week over an interval of about 4 weeks of data, i.e. a sliding solution in which the reference at the beginning of the computation interval ensures continuity with UTC, when available. It is disseminated through daily values of [*UTC*r – *UTC*(*k*)] published at one-week intervals on the Wednesday afternoon, providing access to results up to the preceding Sunday.

The stability of UTCr is expected to be about comparable to that of UTC because the interval of calculation covers one month approximately, the weighting procedure is the same as for UTC, and the participating laboratories are expected to represent at least about 50% of the clocks in UTC and 70% of the total clock weight in UTC. Finally the accuracy is ensured by steering to UTCr to UTC based on the differences observed over the most recent common interval. The process can be summarized as follows:

- A stability algorithm provides an ensemble scale that we here name EALr;
- UTCr is derived from EALr by a steering function f.

$$UTCr = EALr + f(t) \quad (1)$$

The computation can be split in four steps, which are briefly described in the following sections.

B. *Data reporting and checking*

UTCr is based on daily data, both for clock and time transfer, which must be reported daily by contributing laboratories, in practice the data of day D must be uploaded before day D+2, 12:00 UTC. Each laboratory uses an individual account on the ftp server, which is different from the account used for UTC, and is created when the laboratory indicates its intention to participate. Standard file naming conventions must be respected, see ftp://tai.bipm.org/UTCr/Documents/ for guidelines.

In operational use, it is expected that no interaction should happen with laboratories for data correction, etc…. Therefore a number of tasks are automatically carried out in this step:

- detect the input data and check the format of data file, as recognized through the file names.
- report on unknown or new data file. Detection of new files triggers a manual intervention to allow the inclusion of the new data in the data set;
- report on known data file.

C. Computation of the time links

For the computation of UTCr, time links are so far based only on GNSS code data provided in the CGGTTS format [2]. They may be expanded later to include Two Way satellite time transfer and possibly GNSS phase and code solutions. GNSS code data are processed using the Rapid Precise Orbits and clocks products of the International GNSS Service (for GPS) and of the IAC analysis center (for GLONASS), all of which are available in less than one day. Procedures have been developed to allow automatic treatment, particularly for what concerns the detection and correction of possible time steps to avoid interpolation errors.

D. Stability algorithm

The stability algorithm is similar to ALGOS [3, 4, 5] used for TAI. The ensemble scale EALr is

$$EALr - h_j(t) = \sum_{i=1}^{N} w_i \left[h_i'(t) - x_{i,j}(t)\right] \qquad (2)$$

where N is the number of participating clocks, w_i the relative weight of clock H_i, $h_j(t)$ is the reading of clock H_j at time t, $x_{ij} = h_j - h_i$, and $h'_i(t)$ is the prediction of the reading of clock H_i that serves to guarantee the continuity of the timescale. At this stage, only a linear prediction has been implemented, a marked difference with ALGOS for which a quadratic prediction has been in use since August 2011 [6].

The computation interval is between 27 and 31 days, as it starts with a "TAI standard date" (i.e. a Modified Julian Day ending with 4 or 9) and it ends with the last day of the week under computation. Similar to the ALGOS algorithm, the clock weights are determined from the clock instability computed over the computation interval and (up to) eleven 30-day intervals preceding it. Three other rules are applied, that modify the weights obtained from the computed instability:

- If less than four past intervals are available, a null weight is attributed to the clock;
- The maximum weight of a clock is set at 2.5/N;
- A test for "abnormal behavior" is implemented, similar to the one in ALGOS.

After these rules have been applied, the weights are renormalized and the procedure is iterated until convergence.

E. Steering to UTC

The steering of UTCr to UTC is based on a weighted average of the differences $D(t_j)$ between UTC and UTCr computed at the dates t_j as:

$$D(t_j) = \sum_{k=1}^{N} W_k\big([UTCr - UTC(k)](t_j) - [UTC - UTC(k)](t_j)\big) \qquad (3)$$

where W_k is the total weight of the laboratory k in the UTCr calculation. The steering function $f(t)$ is a linear function adjusted to the ensemble of $D(t_j)$. It is planned that each month, when UTC is available, a new function $f(t)$ is calculated and is then applied until the next UTC calculation becomes available. This steering procedure is under study and will be reviewed after the experimentation period of UTCr computation.

III. Implementation of UTCr

The announcement for a pilot experiment was sent to all contributing laboratories in September 2011. By the end of November 2011, 48 laboratories representing 86% of the clock weight in UTC indicated their intention to participate by sending daily clock and time transfer files.

The regular data reports started on January 1st 2012, and the first weekly computation was carried out for the 5th week of 2012, labeled 1205 (the label YYWW identifies the WW th week of year 20YY), and was published on February 27, 2012. "Operational" publication started with week 1208, published the next Wednesday on February 29th 2012, and has continued since that time. The results are published every Wednesday before 18:00 UTC on the web page ftp://tai.bipm.org/UTCr/Results/.

The calendar of publication of UTC is monthly and follows the list of standard dates (MJD ending by 4 or 9), while that of UTCr is weekly and follows the civil week, see an illustration in Figure 1. This has some implications on the steering of UTCr which must be based on an extrapolation of the observed past differences between UTC and UTCr, see an example in the results given in Section IV-A.

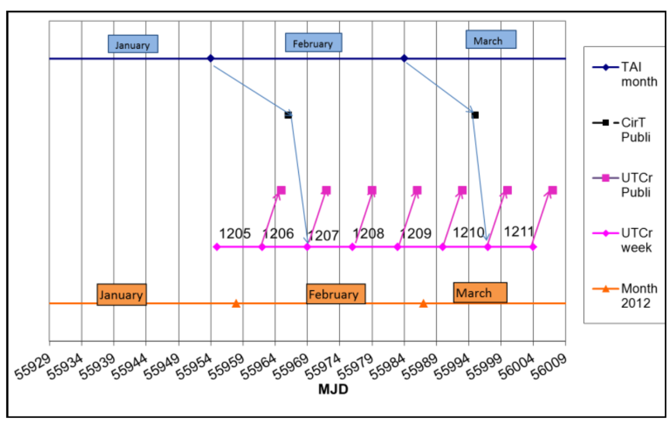

Figure 1. Sequence of events for the computation of UTC and UTCr. The second line from bottom indicates the week numbers for UTCr computation and their date of publication. The top line shows the TAI months in 2012 where the standard dates are indicated in the vertical grid. The line below indicates the date of publication of the corresponding Circular T, e.g. showing that the January Circular is available for the 1206 UTCr computation, and the February Circular for the 1210 UTCr computation.

IV. COMPARISONS OF UTCr WITH UTC

In the following sections, we report comparisons of UTCr with UTC based on the first weeks of UTCr computation.

A. Comparison of the results

The direct comparison of UTCr to UTC is based on the $D(t_j)$ values as given in (3). Figure 2 shows this direct comparison for three months (February to April 2012). In the first two months, a drift can be clearly seen. It is due to the absence of steering in the first weeks of the UTCr computation, until MJD 55989 in week 1209. Subsequently, a default in the steering function which was computed from the February UTC values and applied in March failed to correct the drift, affecting all values from MJD 55994 until MJD 56024 in week 1214. This was corrected only for the week 1215, when the March UTC values became available. The drift is thought to be due partly to the linear prediction used in UTCr whereas a quadratic prediction is used for UTC [6], but also partly to the intrinsic instability of the clock ensemble used for UTCr, which varies from week to week. Therefore it can be expected that using a quadratic prediction in UTCr could reduce the difference between UTCr and UTC, as well as using a steering function experimentally determined as indicated in Section II-E. The steering procedure is one of the main topics to be studied during the pilot experiment phase.

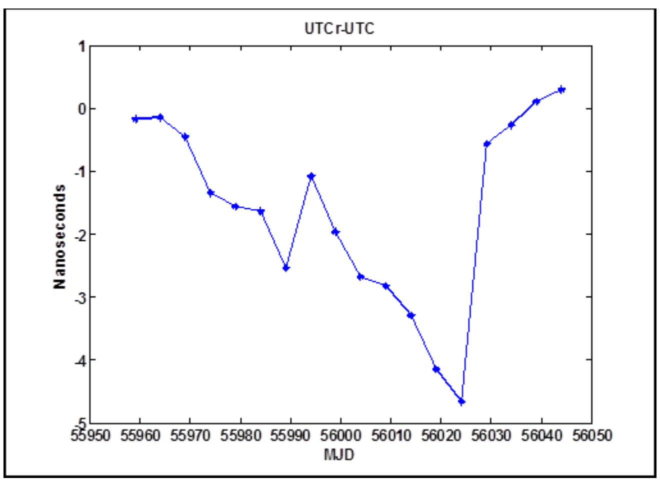

Figure 2. Comparison of UTCr to UTC over three months (see text for details)

B. Comparison of weights

Based on the UTCr computations in four weeks in February 2012, some 32 to 36 laboratories participate to UTCr (vs. 69 in UTC) and more than 25 have some weight in UTCr (vs about 50 in UTC). From Figure 3, we see that many of the laboratories which have a significant weight in both UTC and UTCr have a larger relative weight in UTCr, as expected because each clock has a larger weight due to the reduced number of clocks in UTCr compared to UTC.

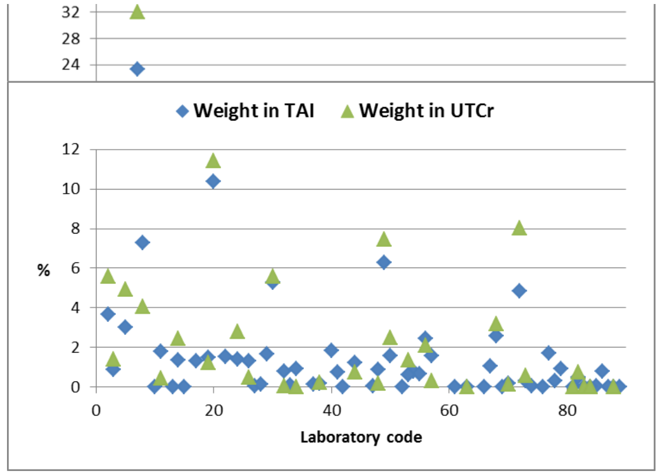

Figure 3. Average weights of the laboratories participating to the four UTCr computations in February 2012 (triangles) compared to their weight in the February UTC computation (diamonds).

C. Comparison of the clock ensemble

Comparing the clock populations and statistics for UTCr in four weeks in February 2012 and for the February UTC computation, we note that:

- 32 UTC laboratories, which clocks make 86% of the UTC weight in February, participated to the four UTCr computations;
- Some 60% of the UTC clocks are in UTCr (note that their total weight in the February UTC computation is lower than the 86% mentioned in the preceding bullet, because not all UTC clocks are reported for UTCr);
- The maximum weight w_{max}, which is computed with the same formula as 2.5/N, is therefore higher in UTCr than in UTC;
- The proportion of clocks reaching w_{max} is slightly lower in UTCr than in UTC;

TABLE I. CHARACTERISTICS OF THE CLOCK ENSEMBLES FORMING UTCR AND UTC IN FEBRUARY 2012

	UTCr	UTC
N clocks for weight	210	360
Max weight w_{max}	1.2%	0.7%
1-month stability at w_{max}	$4.5\text{-}4.7\text{x}10^{-15}$	$4.8\text{x}10^{-15}$
Total weight @ w_{max}	31-37%	40%

We can infer that UTCr is about 20% less stable than UTC, considering that it is based on 60% of the clocks with similar characteristics (see [7] for an estimation of the 1-

month instability of UTC). Table I summarizes some comparisons of the clock ensembles of UTCr and UTC over February 2012.

V. Conclusion

UTC contributing laboratories have been invited to participate on a voluntary basis to a pilot experiment to generate a rapid realization of UTC named UTCr. The pilot experiment started in January 2012, with the target of producing a report for the 19th meeting of the Consultative Committee for Time and Frequency in September 2012. A final decision on the routine production of UTCr will be taken end of 2012.

The first weeks of the pilot experiment have shown that it is possible to perform an automatic computation and a rapid publication of UTCr, while maintaining metrologic quality of the rapid realization.

UTC continues to be calculated and published as before the advent of UTCr, however, it will benefit from UTCr through a shorter latency of publication due to anticipated data checking and pre-processing and a possible better quality of data from contributing laboratories from an early detection of problems.

Acknowledgment

We thank the time laboratories for their participation to the UTCr pilot experiment.

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