International time and frequency comparisons in real time: recent results

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Abstract **— Within the Sistema Interamericano de Metrologia (SIM) region, a time comparison network, SIMTN, has been developed. The SIMTN continuously compares the time scales of SIM members and publishes measurement results in near real-time. The measurements are made with Global Positioning System (GPS) common-view and all-in-view techniques, and data are exchanged and published via the Internet every 10 minutes. As of January 2012, the time scales of national metrology institutes (NMIs) located in 17 nations have joined the SIMTN. The resources of these local time scales are combined to generate the SIM Time Scale (SIMT), which publishes new data every hour via the Internet. These hourly updates show the current time difference between SIMT and the local time scales maintained by each SIM NMI, known as SIMT(*k*).**

Index Terms **— Clock comparison, time scales**

I. The SIM Time Network (SIMTN)

A time comparison network (SIMTN) has been developed by the SIM Time and Frequency Metrology Working Group (SIM TFMWG) with the support of the Organization of American States (OAS). The SIMTN continuously compares the time scales of SIM NMIs to each other, and produces measurement results in near real-time. The comparisons are performed via the Global Positioning System (GPS) common-view and all-in-view techniques, and data are exchanged via the Internet. As of January 2012, SIM NMIs located in 17 nations have joined the network. SIMTN servers located in Canada, Mexico, and the United States host identical software that process and display measurement data whenever requested by a user. All three servers are linked from the web site of the SIM TFMWG at: http://tf.nist.gov/sim

Each server publishes web pages that display a real-time grid that contains the most recent time differences between SIM NMIs. The grids are updated every 10 minutes. When a user "clicks" on a time difference value displayed on the grid, a phase plot of the comparison for the current UTC day will appear. The phase plots can include up to 200 days of data, and the Time deviation and Allan deviation values for the selected data are automatically calculated and displayed.

The SIMTN allows all participants to instantly compare their time scales to each other. This benefits all SIM NMIs, including those that already participate in the CIPM CCTF-K001.UTC key comparison and contribute to the computation of the official world time scale, Coordinated Universal Time (UTC). The UTC contributors can check the performance of their local time scales without waiting for the monthly *Circular-T* report published by the Bureau International des Poids et Mesures (BIPM). Another advantage of the SIMTN is that data are reported every 10 minutes, as opposed to every five days in the case of the *Circular-T*. The more rapid dissemination of data makes it easier to identify short-term time scale fluctuations and to quickly identify and solve problems. A description of the SIMTN and an analysis of its performance are provided in [1]. Reference [2] discusses the benefits that the SIMTN provides to SIM NMIs.

II. SIM Time Scale (SIMT)

About 25 cesium clocks and 10 active hydrogen masers are included in the resources of the SIMTN. This large number of high performance atomic clocks made it attractive to generate an international time scale for the SIM region, now known as SIMT. SIMT was designed with several characteristics in mind, specifically i) to be produced and available in near real-time, ii) to be a virtual time scale (with no physical signal), iii) to include each individual NMI time scale as a single "clock" in the SIMT ensemble, and iv) to avoid intentional steering to any external reference.

The development of SIMT began at CENAM in early 2008 [3] and the time scale has been generated since 2009. After several years of refinement, SIMT has become an easy-to-access reference standard for monitoring the performance of local SIM time scales in the short, medium and long term. The ability of SIMT to detect short term anomalies is especially useful when compared to UTC, which is insensitive for short term (shorter than 5 days) fluctuations.

The algorithms that generate SIMT are similar in many respects to those used at NIST [4] and CENAM [5] to generate the UTC(NIST) and UTC(CNM) time scales, respectively. In such algorithms exponential filtering is used to predict the time and frequency differences of clocks with respect to the averaged time scale. In addition, the weighting procedure is a dynamic process based on the frequency instability of clocks, as estimated with the Allan deviation. The SIMT weighting procedure uses different criteria, however, than the procedures utilized by local time scale. For SIMT, the weighting criterion is the inverse of the Allan deviation, $\sigma_y(\tau)$, which is computed from the previous $\tau = 10$ days of measurements. The long averaging period was

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selected to minimize the influence of GPS time transfer noise on the computation. There is also an "accuracy" factor that contributes to the SIMT clock weights, computed as $1 / \Delta f$, where Δf is the frequency deviation of the NMI time scale.

There are four local SIM time scales that are generated by multi-clock ensembles; located in Brazil (ONRJ), Canada (NRC), Mexico (CENAM), and the United States (NIST). The remaining SIM time scales are generated by the output of a single clock, and are less stable. For this reason, the ONRJ, NRC, CENAM, and NIST time scales are allowed to have a weight as large as 40 % in the SIMT computation, whereas the single clock time scales are limited to a maximum weight of 10 %. Local time scales that do not include at least one cesium clock or hydrogen maser are compared to SIMT, but are not allowed to contribute to its computation.

III. COMPARISON RESULTS

The SIMTN publishes $(N^2 - N) / 2$ time difference values every 10 minutes, where N is the number of SIM time scales. The comparison uncertainty ($k = 2$) is typically less than 15 ns [1]. In addition, N time differences that show the current time difference between SIMT and SIMT(k) are published every hour.

As an example of SIMT performance, Fig. 1 shows time differences of the CENAM time scale during the 500 day period from 55400 MJD to 55900 MJD. The green line on the graph corresponds to the time differences of the CENAM time scale with respect to UTC as published in the *Circular-T* (one value every five days). The blue line corresponds to the time differences of the CENAM time scale with respect to the SIMT values published every hour. Finally, the red line corresponds to the time differences of the CENAM time scale with respect to SIMT at five day intervals (to match the UTC interval).

Figure 1 shows that there has been good agreement between the UTC and SIMT data since about MJD 55550. The measured frequency stabilities of the CENAM time scale when compared to UTC and SIMT are in close agreement, suggesting that SIMT serves as a nearly equivalent reference to UTC for stability measurements. With the exception of NIST, the other SIMTN members that contribute to UTC can also utilize SIMT as a nearly equivalent reference. SIMT is currently not sufficiently stable to measure the stability of UTC(NIST) unless very long averaging periods (multiple months) are used. UTC has many obvious advantages that make it more stable than SIMT, including more clocks, lower noise time transfer links, and frequency corrections that are applied from cesium fountain primary standards. However, SIMT remains useful to NIST and all SIM members as an instantly accessible time scale that complements UTC.

IV. CONCLUSIONS

The SIMTN has operated continuously since 2005, and SIMT has been computed since 2009, with values published every hour. SIMT has proved to be a convenient reference for monitoring and evaluating the performance of local SIM time scales. The performance of SIMT is nearly equivalent to UTC when used to measure the stability of most SIM time scales.

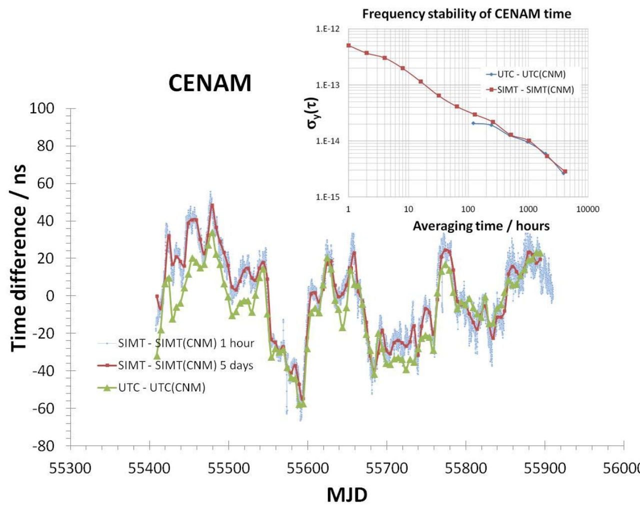

Figure 1. Time differences of CENAM time with respect to UTC and SIMT from 55400 MJD to 55900 MJD.

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