Real-Time Generation of the SIM Time Scale (SIMT) from International Clock Comparisons

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Abstract

The *Sistema Interamericano de Metrologia* (SIM) is one of the world's five major regional metrology organizations (RMOs). The SIM members are the national metrology institutes (NMIs) of the 34 nations of the Organization of American States (OAS). The SIM/OAS region extends throughout North, Central, South America and the Caribbean Islands. About half of the SIM NMIs maintain national standards of time and frequency and participate in international comparisons in order to establish metrological traceability to the International System (SI) of units. The SIM time network (SIMTN) was developed as a practical and cost effective way to automate time comparisons between the SIM NMIs. The SIMTN continuously compares the time standards of SIM NMIs and produces measurement results in real-time by utilizing the Internet and the Global Positioning System (GPS). The SIMTN data are used for the near real-time generation of an international time scale called SIMT. This paper provides a brief overview of the SIMTN and the SIMT.

1. The SIM Region

SIM covers the largest area of any RMO. The SIM region extends throughout North, Central, and South America and the Caribbean, an area that covers roughly 27 % of the world's land mass. The SIM region also contains about 13 % of the world's population. However, as of 2009, about two-thirds of the SIM population (approximately 617 million people) resides in the United States, Brazil, or Mexico. In contrast, 11 SIM nations, mostly islands in the Caribbean region, have populations of less than one million. As of 2009, the per capita gross domestic product (GDP) of the United States and Canada exceeded $38 000 USD, but 15 SIM nations had per capita GDPs of less than $10 000 USD [1]. This large disparity in both population and GDP directly translates into the level of resources that are made available for metrology. Thus, it was essential that both the SIMTN and SIMT were designed with low cost equipment and as few barriers to entry as possible, so that all interested SIM NMIs would be able to participate.

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2. The SIM Time Network (SIMTN)

The SIM Time Network (SIMTN) was developed to encourage and promote cooperation among the SIM NMIs in the field of time and frequency metrology. The SIMTN became operational in May 2005, when comparisons began between the National Institute of Standards and Technology (NIST) of the United States, the Centro Nacional de Metrología (CENAM) of Mexico, and the National Research Council (NRC) of Canada [2]. Since then, the network has expanded to accommodate all interested SIM NMIs. As of February 2011, 16 SIM NMIs have joined the SIMTN, as shown in Figure 1.

Figure 1. The SIM Time Network.

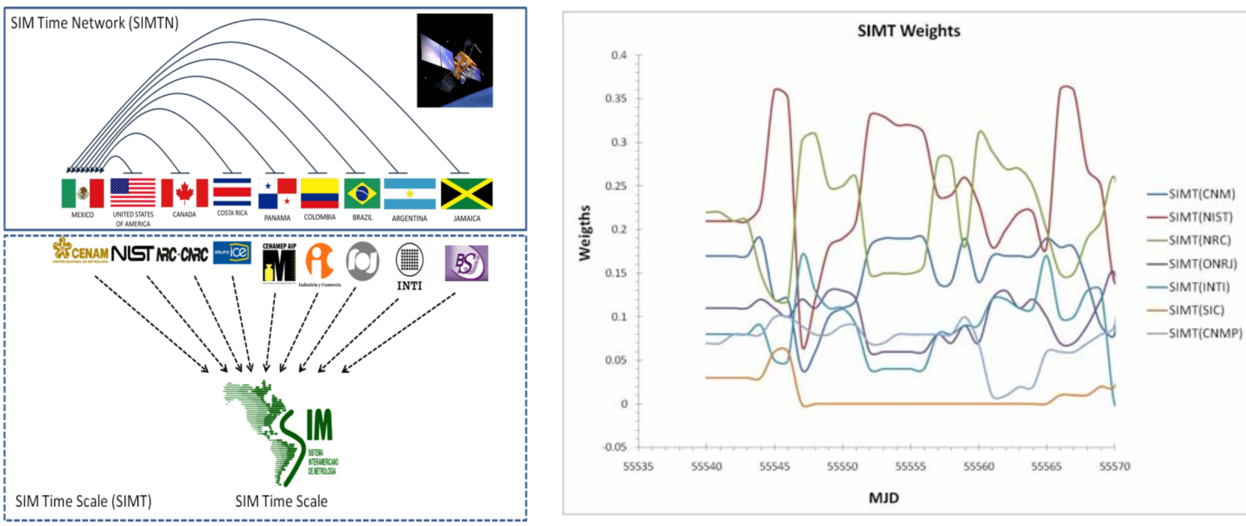
The SIMTN combines two existing technologies, GPS and the Internet. GPS is utilized through a measurement technique called common-view time transfer, which has been applied internationally for decades to compare high accuracy clocks located at remote sites. The common-view technique requires the measurements made by all of the laboratories involved in a comparison to be gathered in one place before the results can be processed. The Internet serves as an ideal medium for transferring measurement data and for instantly publishing measurement results. Results of time comparisons between SIMTN participants are currently updated every 10 minutes and can be viewed at: http://tf.nist.gov/sim

3. The SIM Time Scale (SIMT)

The SIM Time Scale (SIMT) is automatically generated from the SIMTN measurements [3]. SIMT is a weighted average of the local time scales, known as SIMT(k), kept at the various SIM NMIs. It is updated every hour, and the time differences, SIMT – SIMT(k), are displayed on the web. As of February 2011, the nine SIM NMIs that operate either ensemble time scales or single cesium clocks are contributing to SIMT. These nine NMIs can now compare their time scales not only to each other, but also to SIMT.

SIMT differs from the Coordinated Universal Time (UTC) scale generated by the *Bureau International des Poids et Mesures* (BIPM) because the NMIs that operate multiple clocks do not submit individual clock data to the SIMT calculation. Each NMI’s time scale is regarded as one “clock”. It also differs from UTC because it is generated automatically generated with no human intervention or manual file management, and because produces more comparison data. SIMT – SIMT(k) values are generated every hour, whereas UTC – UTC(k) values are only generated every five days. However, SIMT is similar to UTC in two respects: it is a true international time scale consisting of national time standards located in multiple countries, and it is a “paper” time scale. No physical clock currently keeps SIMT, although it would certainly be possible to steer a clock to do so.

The algorithm used to compute the SIMT is similar to the one published in [4], but was customized for this application. The SIMT(k) weights for participation in the SIMT computation are estimated dynamically as a function of the inverse of the Allan deviation $\sigma_y(\tau)$, where τ is one day. Figure 2(a) it is a schematic representation of the SIMT algorithm and Figure 2(b) shows the individual weights for the SIMT computation for the time period from 55540 MJD to 55570 MJD. Along with a similar time scale developed between four NMIs in Asia [5], the SIMT scale is one of the few international time scales generated in real time, and to our knowledge is the only international time scale whose results are made publicly available in real time via the Internet.



(a) (b)

Figure 2. (a) Schematic of the participation of nine SIM laboratories in the generation of SIMT. (b) Weights assigned to SIM time scales during the generation of SIMT.

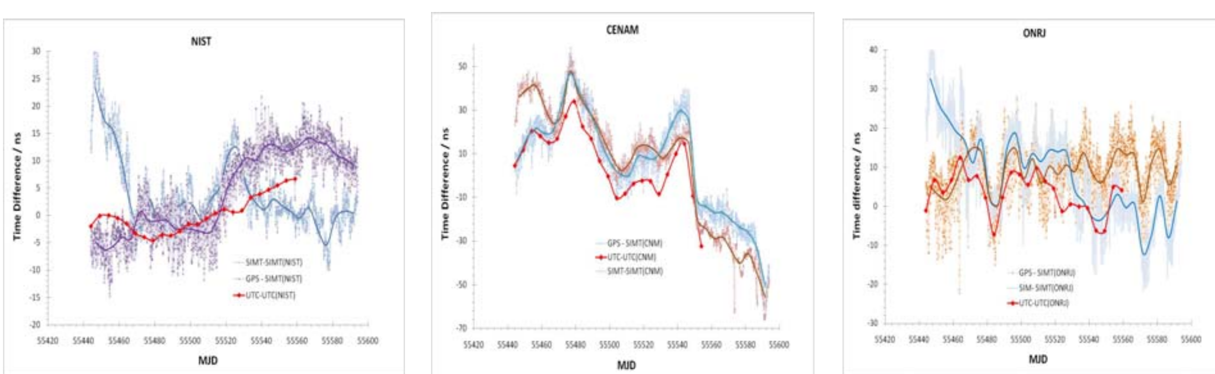
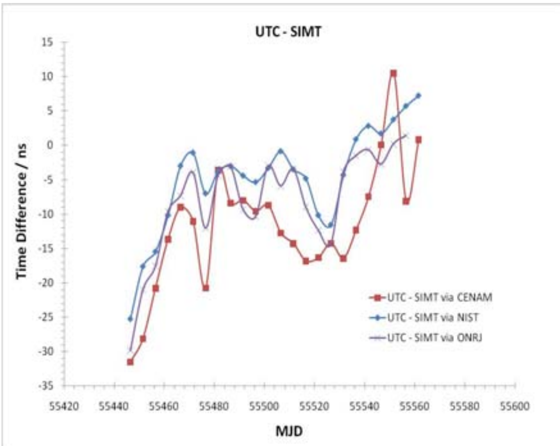
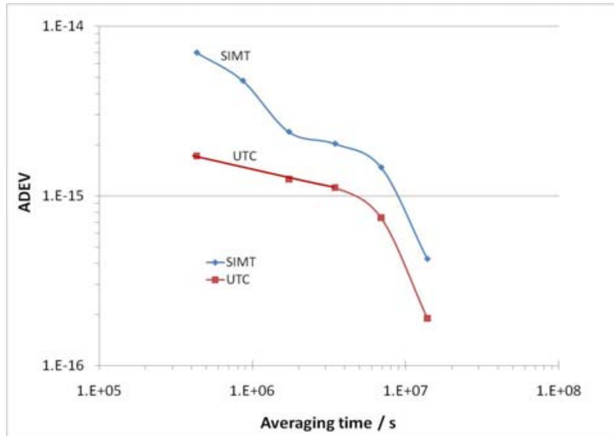


Figure 3. Time differences between time scales of NIST, CENAM and ONRJ with respect to the SIMT, UTC and GPS time scales, respectively.

The NIST time scale is typically the most stable in the SIM region, and thus normally receives the highest weight. To prevent an individual time scale from dominating SIMT, we have established a limit of 40 % for the contribution of a single SIM time scale to SIMT. Figure 3 shows the time differences of the NIST, CENAM, and ONRJ time scales with respect to SIMT, UTC, and GPS time. Figure 4(a) shows the time differences of the SIMT scale with respect to UTC when different SIMT(k) scales are taken as a "common clock". Figure 4(b) shows an estimation of the stability of the SIMT and UTC scales when the three cornered hat method is used for three SIMT(k) scales. The stability of the SIMT can be estimated as $4 \times 10^{-12} / \tau^{1/2}$.



(a)



(b)

Figure 4. (a) Time differences of SIMT with respect to the UTC and GPS time scales along with the UTC – UTC(USNO) time difference. (b) Estimated frequency stability of the SIMT, UTC and UTC(USNO) time scales.

5. Summary

The SIM Time Network (SIMTN) began in 2005, and now continuously compares the time standards of 16 SIM laboratories and publishes the results in real-time on the Internet. The SIMTN reports results every 10 minutes, which makes it easy to identify short-term frequency and time fluctuations and to solve measurement problems. Since 2008, the SIMTN data has been used to generate the SIM Time scale (SIMT). Since the second half of 2009, SIMT has been automatically generated with the results published in real time via the Internet. The frequency stability of the SIMT can be estimated as $4 \times 10^{-12} / \tau^{1/2}$. We are continuing to work to improve SIMT performance. In particular, the criteria used to assign weights to the individual SIMT(k) scales can be improved.

6. References

[1] CIA World Factbook, https://www.cia.gov/library/publications/the-world-factbook/index.html, (accessed February 18, 2010).

[2] M. A. Lombardi, A. N. Novick, J. M. López-Romero, J. S. Boulanger, and R. Pelletier, "The Interamerican Metrology System (SIM) Common-View GPS Comparison Network," *Proc. of the Joint IEEE Int. Frequency Control Symp. and the Precise Time and Time Interval (PTTI) Systems and Applications Meeting*, Vancouver, BC, Canada, 2005, pp. 691-698.

[3] J. M. López-Romero, N. Díaz-Muñoz, and M. A. Lombardi, "Establishment of the SIM Time Scale," *Proc. 2008 Simposio de Metrología*, Querétaro, México, October 2008.

[4] M. Weiss and T. Weissert, "AT2, A New Time Scale Algorithm: AT1 plus Frequency Variance," *Metrologia*, **28**, January 1991, pp. 65-74.

[5] S. Lee, "Real-time formation of a time scale using GPS carrier-phase time transfer network," *Metrologia*, **46**, December 2009, pp. 693-703.

[6] BIPM web site (http://www.bipm.org). The site contains an archive of past *Circular-T* publications.