The SIM Time Network

and its Contributions to Metrology in the Americas

The SIM Time Network (SIMTN) has been one of the great success stories of the *Sistema Interamericano de Metrologia* (SIM), a regional metrology organization (RMO) that includes the 34 member nations of the Organization of American States (OAS). The SIMTN has made it easy for national metrology institutes (NMIs) throughout the SIM region to participate in international comparisons and to coordinate their time standards. It provides continuous, near real-time comparisons between SIM NMIs by utilizing both the Internet and the Global Positioning System (GPS). This article provides an overview of the SIMTN, examining both the technology involved and its contributions to metrology in the Americas.

Background

Like its fellow RMOs, SIM works to ensure the uniformity of measurements throughout a large section of the world by establishing traceability to the International System of units (SI). SIM working groups review the quality systems of NMIs and their calibration and measurement capabilities. They also organize regional comparisons that help the NMIs of small and developing nations maintain standards at the level of accuracy that is needed to support their economy.

Of course, each RMO faces its own unique challenges, and SIM faces several. SIM is the largest of all RMOs in terms of land area (Figure 1), and there is a large variation in both the populations of the SIM nations and the strength of their economies. The SIM region extends throughout North, Central, and South America and the Caribbean, an area that encompasses roughly 27 % of the world's land mass and some 14 % of its population (an estimated 920 million people as of 2007). However, about two-thirds of the people in the SIM region (approximately 600 million people) reside in the United States, Brazil, and Mexico. In contrast, 12 other SIM nations, mostly islands in the Caribbean region, have populations of less than one million. As of 2007, the per capita gross domestic product (GDP) of the United States and Canada exceeded $38,000 USD, but ten SIM nations had per capita GDPs of $7,000 USD or less. This disparity in population and money directly translates into the level of resources that are made available for metrology. For example, NIST has about 40 full-time professionals employed in its time and frequency division, but many SIM NMIs are fortunate if even one metrologist is free to focus on time and frequency measurements.

The concept of the SIMTN was first discussed informally at the National Institute of Standards and Technology (NIST) in 2003. At the time of these discussions, most of the SIM cooperation in time and frequency had been between the three North American NMIs; NIST, the National Research Council (NRC) of Canada, and the Centro Nacional de Metrología (CENAM) of Mexico. NIST and NRC already had long standing reputations as major timing laboratories. CENAM was a relatively new NMI that was formed in 1994 and had made rapid progress. With the exception of laboratories in Brazil and Argentina, the other NMIs in the SIM region were essentially unknown in the international time and frequency community, and had little or no previous interaction with NIST, NRC, or CENAM.

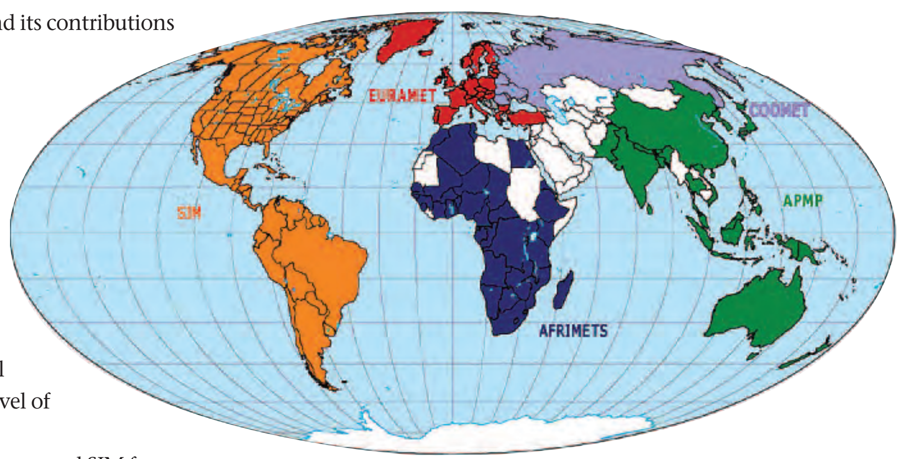

Figure 1. The world's regional metrology organizations (SIM is in orange).

In July 2004, representatives from NIST, CENAM, and NRC met in Ottawa, Canada to discuss ways to link the NMIs of the Americas together, so that as many as possible could establish measurement traceability to the SI. To establish traceability, each SIM NMI would first have to participate in international comparisons. The time and frequency community has an established vehicle in place for organizing international comparisons, because the *Bureau International des Poids et Mesures* (BIPM) key comparisons are used to generate Coordinated Universal Time (UTC). However, not all SIM NMIs are able to participate in the BIPM key comparisons. Some have not signed the BIPM Mutual Recognition Agreement (MRA), and others lacked the resources, training, experience, and contacts that are required to participate. For these reasons, the discussion in Ottawa focused on developing a new mechanism for international comparisons that had as few barriers to entry as possible. Thus, the SIM time network (SIMTN) was born.

The design goals for the SIMTN were:

- To encourage cooperation and communication throughout the SIM region by building a network that allowed even the smallest labs to compare their standards to those of the rest of the world.
- To choose equipment that was low cost and easy to install, operate, and use, because SIM NMIs typically have limited resources and small staffs.

Figure 2. The SIM Measurement System

- To make measurements with uncertainties small enough to characterize the best standards in the SIM region. This meant that the measurement uncertainties had to be as small, or nearly as small, as those of the BIPM key comparisons.
- To report measurement results in near real-time, without the processing delays of the BIPM.
- To build a "democratic" network that favored no single laboratory or nation.

Once the design goals were established, the development of the network quickly proceeded. SIM measurement systems were developed at NIST and delivered to CENAM and NRC in the spring of 2005. The first comparisons began in May of that same year. [1, 2, 3]

Description of the SIM Time Network

The SIMTN consists of a group of common-view GPS measurement systems that are connected to the Internet. The measurement systems (Figure 2) measure the time standard located at each NMI by comparing it to signals received from the GPS satellites. The measurement results are then sent to file servers located at NIST and CENAM (a third server at NRC is planned). The measurement systems and servers were paid for by either the OAS or the NMIs. Excluding labor, the entire network in its present state has cost about $100,000 USD, a very modest price for such a major undertaking.

The common-view GPS technique used by the SIM systems is well established, and variations of this technique have been used by the BIPM for their key comparisons since the 1980s. The common-view technique is quite simple and works well. The obvious best way to measure the difference between two time standards would be to locate them in the same laboratory and directly compare them to each other. Of course, national time standards must remain in their respective countries, and in the case of SIM the distance between them can be quite far; nearly 9000 km in some cases. Since it is impossible to make a direct comparison, the solution is for each NMI to compare its standard to signals that all of the laboratories can receive, such as the signals from the GPS satellites (the SIM system can receive up to eight satellites at once). The satellite signals are not used as a timing reference, but simply as a transfer standard. When the measurements recorded at two sites are subtracted from each other, the satellite time falls out of the equation, and what remains is the time difference between two NMIs.

The main shortcoming of the common-view technique is that the results are often not known until long after the measurements are made, due to the time required to exchange and process the data. The SIMTN solves this problem by exchanging and processing data "on the fly" and then displaying the measurement results in near real-time. All systems transfer data every ten minutes to Internet servers that process the results within a fraction of a second. The measurement results can be viewed with any web browser, so that no special software is needed, and no training is required. The SIMTN favors no individual laboratory or nation. All members (as well as the general public) can view the results of all comparisons.

The web site of the SIM Time and Frequency Metrology Working Group (http://tf.nist.gov/sim) includes a real-time grid (Figure 3) that shows the most recent time differences between SIM NMIs. The grid receives new data every ten minutes, and refreshes automatically every five minutes. If a user clicks on one of the time difference values displayed on the grid, a graph of the comparison for the current day will appear in their web browser.

The real-time measurements allow all network participants to instantly compare their time standards to each other. This benefits all SIM NMIs, including those that already participate in the BIPM key comparisons and contribute to the computation of Coordinated Universal Time (UTC). The UTC contributors can now view interlaboratory data without waiting for the BIPM's monthly *Circular-T* report, which includes results that are typically from two to seven weeks old at the time of publication. Another advantage is that data are reported every ten minutes for the SIMTN, as opposed to every five days in the case of the

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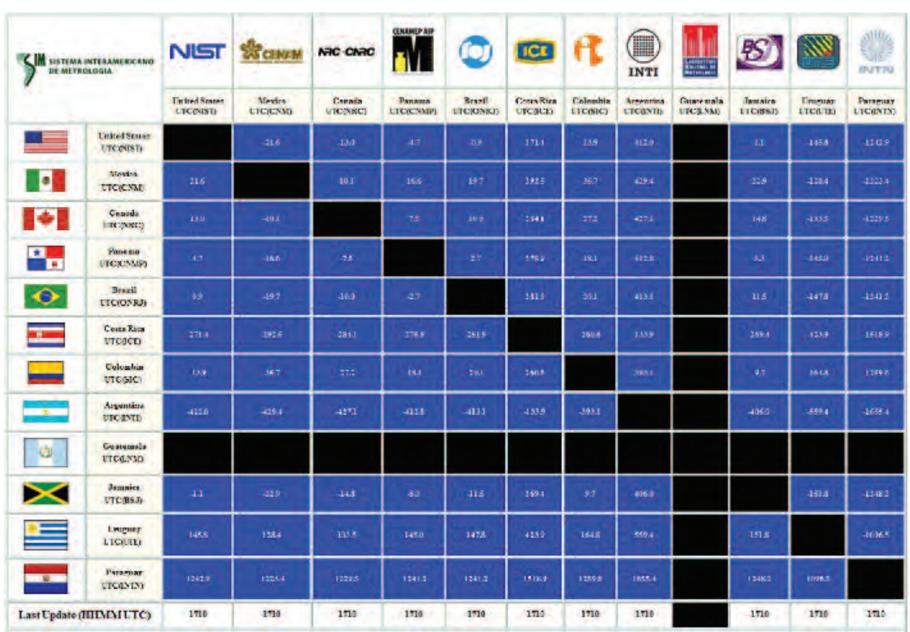

Figure 3. The SIM Real-Time Measurement Grid.

Circular-T. This makes it easier to identify short-term fluctuations, and allows measurement problems to be solved more quickly.

Even though the measurements are made in near real-time, the measurement uncertainty is essentially equal to the BIPM comparisons that involve GPS links. The time uncertainty ($k = 2$) is typically less than 15 ns, and the frequency uncertainty ($k = 2$) is about 5×10^{-14} after 1 day of averaging. [2, 3]

Current and Future Membership

About half of the SIM NMIs now operate, or plan to establish, a time and frequency laboratory. Twelve NMIs have been sent SIM time and frequency measurement systems, and 11 (as of February 2009) are now engaged in continuous international comparisons. Four additional NMIs have expressed interest in joining the network, and will be added as soon as possible. A map of the SIM region showing the current and known future members of the network is provided in Figure 4, and Table 1 provides a list. We anticipate that other SIM NMIs will also be interested in establishing a time and frequency laboratory, and that additional requests to join the network will eventually be received.

Table 1 also lists the type of national time and frequency standard maintained by each SIMTN member. NIST and the other leading timing laboratories around the world maintain UTC time scales that consist of an ensemble of cesium oscillators and/or hydrogen masers. Four SIM NMIs operate ensemble time scales: NIST, NRC, CENAM, and the National Observatory Rio de Janeiro (ONRJ) in Brazil. [4] The other SIM NMIs maintain either a cesium oscillator, a rubidium oscillator, or a GPS disciplined oscillator (GPSDO) as their primary standard.

Figure 4. A SIM map showing the locations of the current (light) and future members (dark) of the network.

Contributions of the SIMTN to Metrology in the Americas

The SIMTN has benefitted the overall state of metrology in the Americas in many ways. Here are some highlights:

- **Improved Time Coordination** - SIM NMIs now keep their standards in close agreement with the standards maintained in the other countries. The NMIs with ensemble time scales, and several others with cesium standards, now routinely keep time within 50 ns of each other. To illustrate this, Figure 5 shows the results of a comparison between the time scales of CENAM and NIST for the 20-month period beginning June 1, 2007 and ending January 31, 2009. The daily values from the SIMTN have error bars showing an estimated uncertainty ($k = 2$) of 12 ns. Values from the BIPM *Circular-T* are shown at five-day intervals, and fall within this uncertainty. Note that the time difference between NIST and CENAM never exceeded 50 ns.
- **Definition of Calibration and Measurement Capabilities (CMCs) –** A goal of the SIM effort is to have all NMIs develop quality systems and to submit their calibra-

Country	NMI	Member of SIM Network	National Standard
Argentina	INTI	Yes	Cesium
Brazil	ONRJ	Yes	Time Scale
Canada	NRC	Yes	Time Scale
Chile	INN	Future	Rubidium
Colombia	SIC	Yes	Cesium
Costa Rica	ICE	Yes	Cesium
Guatemala	LNM	Yes	Rubidum
Jamaica	BSJ	Yes	Cesium
Mexico	CENAM	Yes	Time Scale
Panama	CENAMEP	Yes	Cesium
Paraguay	INTN	Yes	Rubidium
Peru	INDECOPI	Future	Rubidium
St. Lucia	SLBS	Future	Rubidium
Trinidad/Tobago	TTBS	Future	Rubidium
United States	NIST	Yes	Time Scale
Uruguay	UTE	Yes	GPSDO

Table 1. Current and Future SIM Network Members.

Figure 6. Instructors and Attendees at the December 2005 SIM Training Course in Paraguay.

tion and measurement capabilities (CMCs) to the BIPM Key Comparison Database (KCDB). This database can be found at: http://kcdb.bipm.org/AppendixC/default.asp

A total of 30 timing laboratories are included in the KCDB as of February 2009, but only two are from the SIM region. Ironically, CENAMEP of Panama, a very small NMI, was the first SIM lab to be included, followed by NIST in June 2007. At least four other SIM NMIs are now going through the review process, but some SIM laboratories need to sign the BIPM MRA before becoming eligible for inclusion. Much work remains to be done in this area, but the important first step of building awareness among SIM NMIs has now been taken.

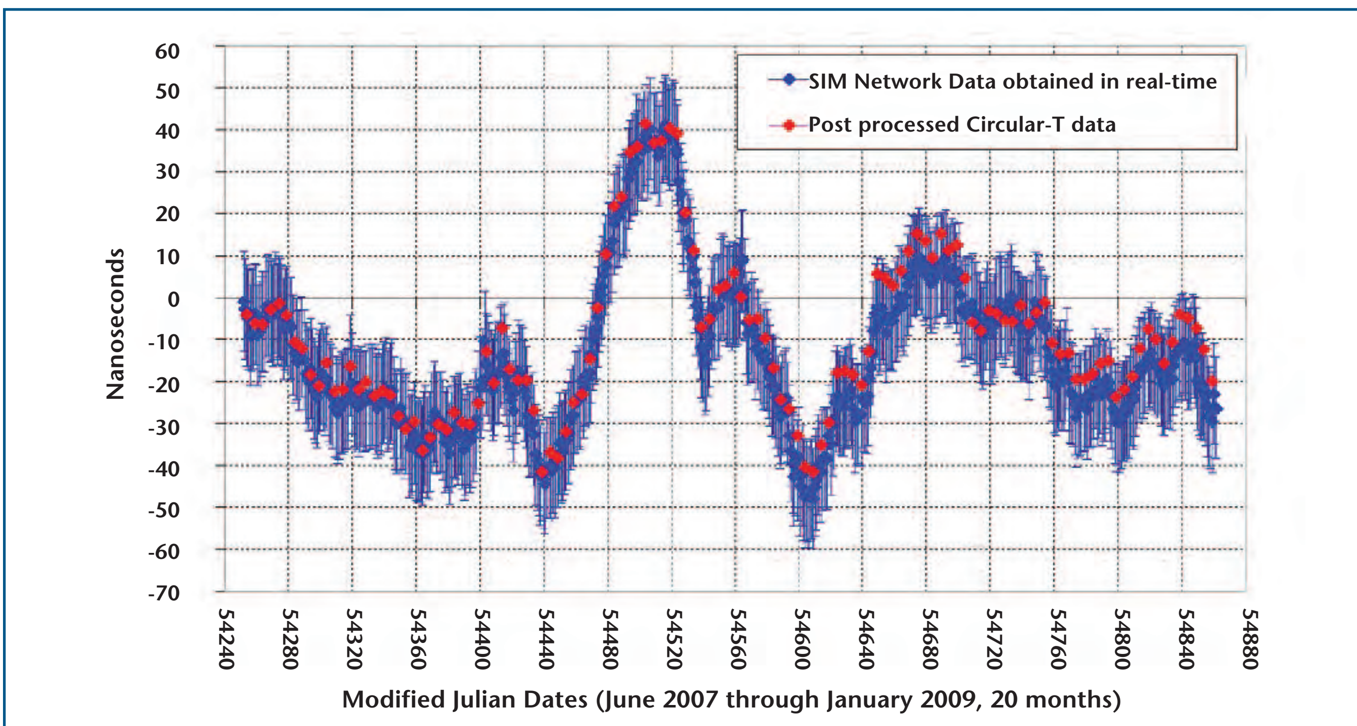

Figure 5. One year comparison between the CENAM and NIST time scales.


ULTIMA HORA

País 19

INTN es el nuevo encargado de fijar el horario oficial

"Se atrasan los relojes"

ITAIPU

Figure 7. Article in Paraguay newspaper about the introduction of the SIMTN.

- **Metrology Education and Improved Communication** - SIM has conducted two four-day time and frequency training classes, and each were attended by over 25 metrologists. The first was held in Asunción, Paraguay in December 2005, and the second was in Buenos Aires, Argentina in February 2008. A third course is planned for late 2009. Figure 6 is a photo of the participants in the course in Paraguay.

  The training effort goes on continuously through emails and phone conversations and the cooperation between the laboratories has been excellent. Several interlaboratory visits have taken place in addition to the training courses described above.
- **The Establishment of a SIM Time Scale** - In late 2008, work began at CENAM on the development of algorithms for a SIM time scale, to be known as *SIM-Time*. This time scale will accept the real-time inputs from each of the participating laboratories, and then generate a composite time scale based on the weighted average of each contributor. When this work is completed, it will be possible for all members of the SIMTN network to compare their standards not only to each other, but also to *SIM-Time*. [5, 6]

Benefits of the SIMTN to SIM NMIs

Each of the 12 nations now participating in the SIMTN has benefitted in numerous ways. A few highlights are listed here:

- The NMIs in Panama and Paraguay have used the SIMTN to gain status as the "official" timekeeper for their country. For example, Figure 7 is a news story that was published in Ascuncion, Paraguay when the SIM system was first turned on at the Instituto Tecnologia y Normalización (INTN) in February 2009.
- The Instituto Nacional de Tecnologia Industrial (INTI) in Buenes Aires, Argentina acquired a cesium oscillator in 2008 and is already participating in the BIPM key comparisons and contributing to Coordinated Universal Time (UTC) using data collected via the SIMTN (several other SIM NMIs contribute to UTC using other systems). The SIM data format differs from the BIPM format, but through the use of conversion software, INTI reported their first measurement to the BIPM in October 2008.
- The National Observatory Rio de Janeiro (ONRJ) in Brazil has a relatively new time and frequency program, but has made rapid progress in recent years. The real-time reporting of the SIMTN has helped ONRJ to evaluate and improve their time scale without waiting for post processed measurement results. ONRJ collaborated with NIST on a 2007 study [4] that demonstrated how the real-time results from the SIMTN compare favourably with the post-processed results from other NIST-ONRJ comparisons, particularly over long averaging times.
- The Superintendencia de Industria y Comercio (SIC) in Bogota, Colombia had operated a time and frequency laboratory prior to the development of the SIMTN, but the SIMTN allowed them to engage in international comparisons for the first time. The SIC program has made rapid progress. The national standard for time and frequency in Colombia had been a rubidium oscillator that was measured by the SIMTN from May 2007 until January 2008, when it was replaced by a cesium oscillator. A second cesium oscillator has been purchased, and SIC reported in October 2008 that they are beginning the development of an ensemble time scale.
- When the SIM measurement equipment arrived at the Instituto Costarricense de Electricidad (ICE) in Costa Rica in March 2007, their national time and frequency standard was a quartz oscillator, accurate to only parts in 10^8. ICE acquired a new cesium standard in August 2008, improving their calibration capability by five orders of magnitude.
- The Centro Nacional de Metrología (CENAM) maintains two SIM measurement systems and a backup file server for the SIMTN. The second measurement system is connected to their new experimental time scale [6], and allows CENAM to compare the experimental time scale to both their original time scale and the other standards in the SIM region. CENAM is applying their time scale algorithms to the formation of a SIM time scale (see previous section), and has exemplified the cooperative spirit of SIM by providing considerable technical support to other NMIs throughout the SIM region.

  In 2007, NIST and CENAM collaborated on a project to synchronize the clocks in the TELMEX communications network in Mexico to the UTC(CNM) time scale. TELMEX is the largest telephone provider in Mexico and serves many millions of customers. The TELMEX telephone network includes eight cesium primary reference clocks, with a pair of cesium oscillators located in each of four different cities in Mexico. The goal of the project was to continuously compare the eight cesium clocks to UTC(CNM), the national time standard in Mexico. The goal was accomplished by building a time network for TELMEX that is similar to the SIMTN, but that uses slightly different hardware and software. Figure 8 is a photograph showing a GPS antenna being installed at one of the TELMEX sites.
- The Centro Nacional de Metrología de Panamá (CENAMEP) in Panama City, Panama is a sterling example of what a small NMI in a small country is able to accomplish. The population of Panama is roughly 1 % of the U. S. population, and CENAMEP had just 12 employees as of 2008. Even so, their laboratory covers all major areas of metrology, and CENAMEP operates two cesium oscillators and contributes to UTC. They also operate a web clock (horaexacta.cenamep.org.pa). The first time service at CENAMEP began in May 2006, shortly after joining the SIMTN. It was a continuous time display broadcast by a Panamanian TV station. Since the entire country resides in one time zone, they simply focused a video camera on a clock driven by their cesium oscillator.

Summary

The SIMTN has been a great success. It has not only accomplished its basic objective of providing NMIs with a convenient way to establish traceability to the SI, but has also led to other benefits that have enhanced time and frequency metrology throughout the Americas. Now that a new spirit of communication and cooperation exists among SIM laboratories, even more progress can be expected in the future.

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Figure 8. GPS installation at a TELMEX site.