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The SIM Time Network - Twenty Years of Operation

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Abstract

The SIM Time Network (SIMTN) was established two decades ago to provide real-time time and frequency comparisons among National Metrology Institutes (NMIs) across the Americas. Since its inception, SIMTN has played a crucial role in strengthening regional time and frequency capabilities by enabling continuous monitoring, promoting traceability to UTC, and supporting the realization of UTC(*k*) time scales. Currently the SIMTN comprises 26 labs. This paper presents a comprehensive overview of the design, operational evolution, and achievements of the SIMTN over twenty years of continuous operation. Key aspects include the initial system architecture based on GPS common-view methods, the deployment of decentralized data centers, and the development of custom software for data acquisition, processing, and dissemination. We discuss the significant upgrades introduced to enhance reliability, automation, and measurement precision, as well as the network's contribution to international timekeeping activities. Finally, we outline the near future prospects for the SIMTN, including dual-frequency receivers to decode both the L1 (1575.42 MHz) and L2 (1227.6 MHz) GPS signals. This allows a measurement of the actual delay of the signals through the ionosphere instead of relying on calculated models. We demonstrate that this approach significantly enhances positioning accuracy and reduces delay variations caused by diurnal fluctuations, enabling time comparisons within the SIMTN with a combined uncertainty (k = 2) of less than 2 nanoseconds.

I. INTRODUCTION

Precise time and frequency measurements are fundamental for science and research. In fundamental physics research, highly accurate atomic clocks provide the foundation for testing the laws of nature, including relativity and quantum theory [1]. These measurements allow scientists to probe minute changes in physical constants and explore new theories that shape our understanding of the universe. In astronomy, precise timekeeping is essential for celestial observations, pulsar timing, and the synchronization of large-scale telescope arrays. Accurate frequency measurements allow for the detection of gravitational waves and the study of cosmic phenomena with unprecedented precision [2]. Furthermore, precision timing plays a crucial role in space missions, enabling accurate satellite navigation and deep-space communication.

Time synchronization is also important to the economy, telecommunications, defense, and metrology [3]. In the economic sector, precise timekeeping ensures the smooth operation of financial transactions, stock exchanges, and banking systems, preventing discrepancies [4]. Without accurate synchronization, financial markets could experience mismatched transaction times, leading to potential losses, inefficiencies or fraud. In telecommunications, synchronization is essential for data transmission, network stability, and efficient communication between devices. Mobile networks, the internet, and satellite communications rely on precise timing to avoid data loss and interference, ensuring seamless global connectivity. Synchronization allows for the efficient allocation of bandwidth, reducing latency and improving the quality of voice and video communications. Emerging technologies such as 5G networks depend on highly accurate timekeeping to optimize data flow and enhance user experiences [5]. The defense sector depends on synchronization for accurate navigation, secure communications, and coordinated military operations. Global Navigation Satellite Systems (GNSS), radar, and encrypted networks require precise timing to function effectively and maintain national security. In metrology, synchronization enables accurate measurement standards, ensuring consistency in industrial production, and international trade. Reliable timekeeping allows for precise calibration of instruments, reducing errors in technological and engineering applications. Industries such as aerospace, healthcare, and manufacturing depend on accurate measurements to maintain quality control and meet regulatory standards. In scientific research, synchronized timekeeping is essential for experiments involving particle physics, astronomy, and quantum computing. Beyond these fields, synchronization is also vital in transportation, energy distribution, and space exploration, highlighting its universal importance in modern society. In transportation, synchronized traffic control systems optimize traffic flow, reducing congestion and improving safety. Rail networks and air traffic control systems require precise timing to coordinate departures, arrivals, and tracking. In the energy sector, synchronization ensures stable power grid operation, balancing supply and demand to prevent blackouts. Finally, in space exploration, synchronized timing is crucial for deep-space communication, satellite positioning, and interplanetary missions.

Overall, synchronization is a foundational element in technological advancement and global infrastructure. As society becomes increasingly interconnected, the demand for precise timekeeping continues to grow, shaping the future of communication, security, commerce, and scientific discovery.

The Inter-American Metrology System (SIM) is an organization that brings together the national metrology institutes of the 34 member countries of the Organization of American States (OAS), covering North America, Central America, South America, and the Caribbean. SIM is a regional organization that promotes metrological cooperation among the National Metrology Institutes (NMIs) of the Americas. Established to enhance measurement standards and ensure international consistency, SIM plays a crucial role in scientific, industrial, and commercial sectors by fostering collaboration and harmonization of metrology practices across the region.

SIM supports the development of accurate and reliable measurement capabilities in member countries, facilitating trade, innovation, and technological progress. Through coordinated activities, research projects, and knowledge exchange, SIM strengthens national metrology infrastructures and ensures compliance with international standards set by organizations such as the International Bureau of Weights and Measures (BIPM) and the International Organization of Legal Metrology (OIML). One of SIM's key initiatives is the Mutual Recognition Arrangement (MRA), which allows member countries to recognize each other's calibration and measurement capabilities, reducing trade barriers and enhancing economic integration. Additionally, SIM promotes training programs, technical assistance, and capacity-building efforts to support emerging metrology institutions in the region. By fostering collaboration and maintaining high metrological standards, SIM contributes to scientific advancement, economic growth, and technological innovation throughout the Americas, reinforcing the importance of precise measurements in a wide range of applications.

SIM member countries are organized into five subregions:

- ANDIMET (Andean countries): Bolivia, Colombia, Ecuador, Peru, and Venezuela.
- CAMET (Central America): Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama.
- CARIMET (Caribbean): Antigua and Barbuda, The Bahamas, Barbados, Dominica, Grenada, Guyana, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, and Trinidad and Tobago.
- NORAMET (North America): Canada, the United States, and Mexico.
- SURAMET (South America): Argentina, Brazil, Chile, Paraguay, and Uruguay.

Additionally, the Physikalisch-Technische Bundesanstalt (PTB) of Germany is an associate member of SIM. It is important to note that although SIM comprises 34 member countries of the Organization of American States (OAS), the level of active participation in different SIM initiatives, such as the SIM Time and Frequency Network (SIMTN), may vary depending on each country's capabilities and available resources.

The SIM Time and Frequency Network (SIMTN) was established in 2005 as part of the Inter-American Metrology System (SIM) to enhance regional cooperation in time and frequency metrology [6]. Its origins trace back to the early 2000s when national metrology institutes (NMIs) across the Americas recognized the need for a coordinated system to compare and disseminate precise time and frequency measurements. Before SIMTN, time synchronization among countries in the region was fragmented, with each nation relying on independent methods to maintain national time scales. To address this challenge, SIM, in collaboration with the National Institute of Standards and Technology (NIST) in the United States, the National Research Council (NRC) of Canada and the Centro Nacional de Metrología (CENAM) of Mexico, initiated a project to interconnect time laboratories using modern internet-based techniques. The goal was to create a robust network that would allow real-time comparisons of national time scales, ensuring traceability to Coordinated Universal Time (UTC) [7]. The development of SIMTN was supported by advancements in remote time transfer methods, including GPS common-view and Two-Way Satellite Time and Frequency Transfer (TWSTFT), enabling high-precision synchronization across vast distances. Since its inception, SIMTN has significantly improved the accuracy and accessibility of timekeeping in the Americas. By fostering collaboration among NMIs, the network has strengthened the region's metrological infrastructure, supporting industries, scientific research, and critical applications such as telecommunications and power grid synchronization [8]. Today, SIMTN continues to evolve, incorporating new technologies to enhance resilience and maintain global competitiveness in time and frequency metrology [9].

II. DESIGN GOALS OF THE SIM TIME NETWORK

Each Regional Metrology Organization (RMO) encounters distinctive operational challenges, and SIM is no exception. Geographically, SIM constitutes the largest RMO (Fig. 1), encompassing a vast and heterogeneous region. The SIM membership spans North, Central, and South America as well as the Caribbean, collectively covering approximately 27% of Earth's landmass and accounting for about 13% of the global population, estimated at 1040 million individuals as of 2025.

However, demographic and economic disparities across the region are considerable. Approximately two-thirds of the SIM population—around 617 million people—reside in just three countries: the United States, Brazil, and Mexico. In contrast, 11 SIM member states, predominantly located in the Caribbean, each have populations of fewer than one million inhabitants, highlighting the diversity in national capacities and resources within the organization.

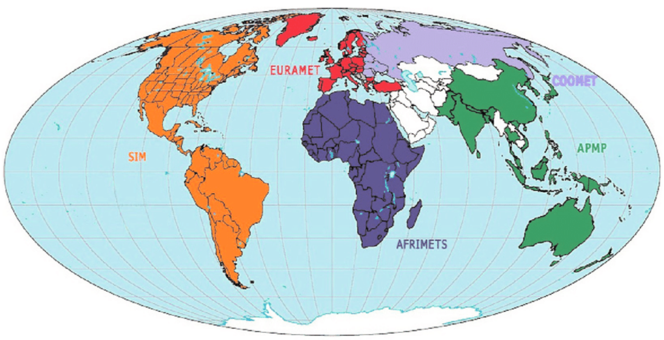

Fig. 1. The world's regional metrology organizations.

The SIM Time and Frequency Network (SIMTN) was established to provide precise, reliable, and internationally traceable time and frequency synchronization across the Americas. One of the primary objectives of SIMTN is to maintain traceability to the International System of Units (SI) by linking national time standards to Coordinated Universal Time (UTC). This ensures that timekeeping across the region adheres to internationally recognized standards. Another key goal is to enable real-time comparisons and monitoring of national time scales. By implementing high-precision measurement techniques, SIMTN enhances the accuracy and stability of time synchronization among participating countries. Redundancy and resilience are also central to the design of SIMTN. The network integrates multiple sources of precise timing signals, ensuring robustness in the event of disruptions. This design minimizes the risk of failures that could affect critical infrastructure, including emergency response systems, air traffic control, and cybersecurity protocols.

Additionally, SIMTN is designed to foster metrological development and capacity-building in Latin America and the Caribbean. By providing technical support, training, and access to advanced timekeeping technologies, SIM strengthens the metrological capabilities of its member countries, allowing them to integrate into the global scientific and technological community. Overall, the SIM Time and Frequency Network plays a vital role in ensuring accurate, reliable, and accessible timekeeping services across the Americas. Through its design objectives, SIMTN enhances regional cooperation and technological progress, of precise time and frequency measurements.

III. SIM TIME NETWORK TECHNICAL CAPABILITIES

The SIMTN operates using the common-view comparison method [10], where observers from all locations use similar or identical measurement systems to compare their local clock or timescale to the clocks on board global positioning system (GPS) satellites. The individual SIM measurement systems comprise a tabletop rack with an LCD monitor and an industrial rack-mount computer chassis equipped with a single-board computer card, a time interval counter (TIC) featuring a single-shot resolution of less than 0.1 ns, and an eight- or twelve-channel GPS receiver. The receivers output a 1 pulse per second (PPS) signal, which is compared to the local clock PPS using TIC. The PPS signal from GPS is a composite output generated from contributions of the clocks on-board the individual satellites in view. To attain the individual clock contributions to the composite output, the messages from the satellite broadcast must be parsed.

When observers at different lab locations each compare their clocks to the same satellite clock, calculations can be made to determine the difference between the lab clocks, and the satellite clock cancels in the equation. By using all the satellites viewed "in common" between two sites, the comparisons can be made with high precision. However, factors such as environment, calibration, coordinates, and multipath all can influence the results and must be included in the uncertainty analysis [8].

All SIM systems are calibrated at the NIST Time and Frequency laboratory prior to shipment to the host SIM NMI. Each calibration lasts 10 days and is performed using the common-clock method across a ~6 m baseline. The calibration results in a single delay constant accounting for the antenna, antenna cable, and receiver delays. This constant is referred to as "Rx Delay" and is entered into the system software prior to shipment.

Custom File Transfer Protocol (FTP) software, installed on every SIM system, uploads data every 10 minutes to servers located at CENAM, NRC, and NIST. This configuration ensures redundancy by maintaining copies of the SIMTN data in three different countries. The servers host identical software that processes common-view data upon user request and are accessible through the SIM Time and Frequency Metrology Working Group website: http://tf.nist.gov/sim. Each server displays a real-time grid showing the most recent time differences between SIM NMIs, updated every 10 minutes and refreshed every five minutes. By clicking on a time difference value in the grid, users can generate a phase plot of the current day's comparison, viewable directly in their web browser. These phase plots can also be adjusted to display data for up to 200 days.

Additionally, results are presented as one-hour and one-day averages, with time deviation (TDEV) and Allan deviation

(ADEV) values automatically calculated for the selected data. Users can also view data in tabular form, with options for 10-minute, one-hour, or one-day averages, which can be copied to a spreadsheet for further analysis. The real-time measurements provided by the SIMTN allow all participants to instantly compare their time standards, promoting efficiency and uniformity across the network with uncertainties below 12 ns [7].

IV. THE SIM TIMESCALE

The SIM Time Scale (SIMT) is a coordinated time reference developed by the Inter-American Metrology System (SIM) to enhance timekeeping precision and synchronization across the Americas [11]. It is generated by integrating time data from multiple National Metrology Institutes (NMIs) within the SIM region, providing a stable and reliable time scale that serves as a reference for scientific, technological, and industrial applications [12]. One of the primary objectives of SIMT is to provide an accurate and continuous time reference that is closely aligned with Coordinated Universal Time (UTC) but reported in near real time (a new point every ten minutes) so that anomaly detection and steering can be accomplished by laboratories in the region. The SIMT is designed to improve interoperability between different national timekeeping systems, allowing for coordination across borders [13].

Another key aspect of the SIMT is its role in scientific research and innovation. It supports metrological advancements by providing a highly stable time scale that can be used for experiments in fundamental physics, space exploration, and geophysics. Accurate timekeeping is essential for measuring gravitational variations, monitoring Earth’s rotation, and enhancing the precision of astronomical observations.

Additionally, the SIMT contributes to regional resilience by offering an independent and robust time scale that can serve as a backup in case of disruptions in global timekeeping services. This ensures that critical infrastructure and national timekeeping systems remain functional even during unexpected events or outages.

V. GROWTH AND CURRENT STATUS OF THE SIM TIME NETWORK

Starting in 2005, NIST began calibrating and sending the measurement systems (referred to as “SIM Systems”) to start building the SIMTN. This effort was supported by the Organization of American States (OAS) and the NIST International and Academic Affairs Office (IAAO), who provided funds to the NIST Time Realization and Distribution group for this effort, and the measurement systems were donated to the SIM labs. At that time, only five SIM labs contributed to UTC. One of the goals of creating this network was to help SIM labs increase their time and frequency capabilities, with the ultimate goal being to contribute to UTC by submitting their timing data to the BIPM. By 2010, there were 16 SIM systems at labs, and they were making real-time comparisons, bet there were only six sites contributing to UTC. By 2015, there were 23 SIM systems, but only seven contributing to UTC. So, the network was growing rapidly, and labs were improving their capabilities, but there were barriers to going further. Many labs were running rubidium atomic oscillators (in some cases, donated by NIST) and steering them manually (see Fig. 2). However, to submit data to the BIPM, a lab must have at least one free-running cesium atomic oscillator and must have a “time-transfer receiver”. This receiver uses the PPS signal from the atomic clock (or time scale) and uses data from its internal GNSS receiver to generate a file in the *Consultative GPS and GLONASS Time Transfer Sub-committee* (CGGTTS) format and upload it to the BPIM server. These receivers could be prohibitively costly, so NIST developed a system named TAI-1, which used similar hardware and software as the SIM system, to generate and upload the files to the BIPM. Six of these systems were sent to labs who were ready to contribute to BIPM and, in 2025, there are 13 SIM countries contributing to UTC and 26 labs with SIM systems, although not all of the systems are actively taking data.

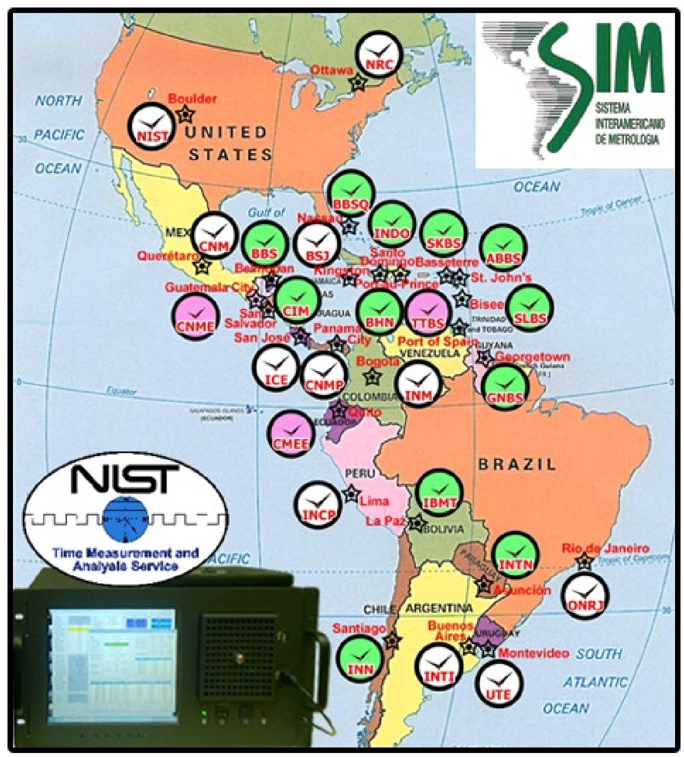

Fig. 2. The SIM Time Network comprises 26 labs. The white clocks represent labs with cesium oscillator(s) or an ensemble time scale; the green clocks represent labs with rubidium oscillators steered to SIMT; the purple clocks represent labs with GPS-disciplined oscillators or undisciplined rubidium oscillators.

By having a national timing infrastructure and international comparisons, labs can proudly disseminate their time signals within their country. One of the first ways that countries start to distribute time is via the network time protocol (NTP). Computers and other devices can send an NTP request and get a timestamp over a wide area network (WAN) accuracy within tens of milliseconds or better. There are currently 16 SIM labs with free NTP services [14]. Fifteen SIM labs have a web clock; a running clock embedded on a website showing the time, referenced to the national lab. Other services may include radio broadcasts, computer time via modem with analog phone lines, precision time protocol (PTP), common-view remote comparisons, two-way satellite time transfer (TWSTT) or low-Earth orbit (LEO) satellite time transfer.

VI. NEAR FUTURE IMPROVEMENTS

Since several improvements have been implemented to the common-view measurement systems at NIST, an effort is underway to replace all the SIM systems with an improved time and frequency measurement system. Originally, the GPS receivers used were only decoding the L1 signal at 1575.42 MHz from the satellites but, in recent years, dual-frequency receivers have been developed which are available for significantly lower cost. These receivers decode both the L1 and L2 (1227.6 MHz) signals. This allows an actual measurement of the delay of the signals through the ionosphere instead of relying on calculated models or post-processed results. This can greatly improve the positioning accuracy and the delay variations due to diurnal fluctuations. Figure 3 shows a phase plot of the common-view comparisons between UTC(NRC) in Canada and UTC(NIST) in the United States. The red (lighter) line shows a comparison of the time scales of the two countries using the original single-frequency measurement systems at both sites, and the blue (dark) line shows a comparison during the same period using the dual-frequency measurement systems. The range of the ten-minutes averages from the original system is 32.2 ns, whereas the range from the new system is 5.5 ns.

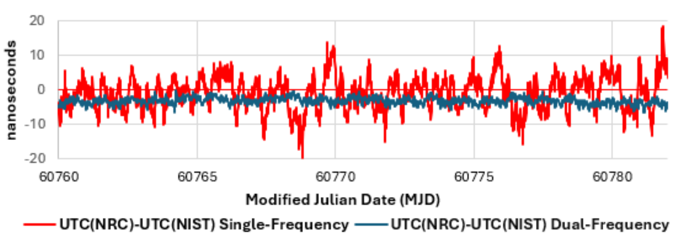

Fig. 3. A phase plot comparing the time scales in the Canada (NRC) and United States (NIST) with common-view measurements from the original (red/lighter) and new measurement system (blue/darker).

The effects on the common-view measurements from environmental fluctuations and multipath have been studied and are significantly reduced from the estimated effects of the single-frequency systems [15]. Table I shows the differences in the uncertainty evaluations of the original system compared to the new system, which was a very thorough review. The combined uncertainty U_C was reduced from ~12 ns to ~2 ns.

TABLE I. A COMPARISON OF MEASUREMENT UNCERTAINTY ESTIMATES OF ORIGINAL SINGLE-FREQUENCY SIM SYSTEM AND THE NEW DUAL-FREQUENCY SYSTEM.

Uncertainty Component	***Single Frequency***	***Dual frequency***
$U_{A,}$ Time Uncertainty	*2.0 ns*	*0.5 ns*
$U_{B,}$ Calibration	*2.0 ns*	*0.35 ns*
$U_{B,}$ Coordinates	*3.0 ns*	*0.15 ns*
$U_{B,}$ Environment	*3.0 ns*	*0.25 ns*
$U_{B,}$ Multipath	*2.0 ns*	*0.5 ns*
$U_{B,}$ Ionosphere	*2.0 ns*	*0.25 ns*
$U_{B,}$ Reference Delay	*1.0 ns*	*0.1 ns*
$U_{B,}$ Resolution	*0.05 ns*	*0.05 ns*
U_C, k= 2	*11.8 ns*	*1.77 ns*

VII. CONCLUSIONS

The SIM Time Network (SIMTN) has established a decentralized, autonomous infrastructure for real-time intercomparisons of UTC(*k*) realizations among National Metrology Institutes (NMIs) within the SIM region. Its architecture, based on GPS common-view methodology, redundant data centers, and standardized processing software, has enabled continuous monitoring and traceability to Coordinated Universal Time (UTC). Near future improvements on the SIMTN will allow continuous monitoring the SIM UTC(*k*) time scales with uncertainties at the near-nanosecond level.

The operational experience accumulated over nearly two decades demonstrates the network's robustness, scalability, and critical role in supporting the dynamic realization of UTC(*k*), enhancing the regional time dissemination capabilities, and contributing to global time coordination efforts. The SIMTN has also been instrumental in fostering technical cooperation and capacity building across participating NMIs, facilitating harmonized procedures aligned with BIPM recommendations.

Future developments for SIMTN foresee the integration of advanced time transfer techniques, such as GPS carrier-phase common-view (CV-PPP). Additionally, upgrades in data validation protocols, automation of anomaly detection, and enhanced real-time processing will further improve the precision, availability, and resilience of the network.

The SIM Time Network constitutes a fundamental regional infrastructure for time and frequency metrology that can provide quality control and support to NMIs internal systems to improve their services. Its continuous evolution will ensure its capacity to meet the increasingly demanding requirements of emerging applications in scientific research, telecommunications, navigation, and other sectors reliant on high-precision timing.

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