Current Status and Future Direction of the SIM Time Network

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Outline

History of SIM Time Network (SIMTN)

Current Status of SIMTN Operation

- laboratories contributing to SIMTN
- primary laboratory standards
- operational status of SIM measurement systems
- CPU and computer operating system status

SIMTN Participants Contributing to Coordinated Universal Time

How the SIMTN Works and System Design Details

Possible Future Design Enhancements to SIMTN Measurement Systems

History

The SIM Time and Frequency Metrology Working Group existed prior to 2004 but was not active. Some key dates:

2004 - Plans for the SIM Time Network (SIMTN) were agreed upon at a meeting at NRC in Ottawa, Canada in June. Software development and planning efforts began at CENAM, NIST, and NRC shortly after that meeting.

2005 – First SIM Time Network (SIMTN) measurements (between CENAM, NRC, and NIST were recorded in May and the first paper was published at the *IEEE Frequency Control Symposium* in August. The SIMTN was perhaps the world's first real-time common-view multi-national time comparison network.

2008 – Work begins on SIM Time Scale (SIMT) at CENAM. First publication was at CENAM Metrology Symposium (Simposio de Metrología) in October.

2009 – SIMT becomes an operational time scale with results published on-line hourly. It was the world's first multi-national time scale computed in real time.

2010 to 2022 – The SIMTN and SIMT have continued to improve and be continuously maintained and remained operational throughout the pandemic. SIM measurement systems are currently located in 26 of the 34 nations of the Organization of American States (OAS).


NRC
NIST
BBSQ
CNM
BHN
INDO
BBS
BSJ
ABBS
SKBS
CNME
SLBS
CIM
ICE
TTBS
GNBS
CNMP
INM
CMEE
INCP
IBMT
ONRJ
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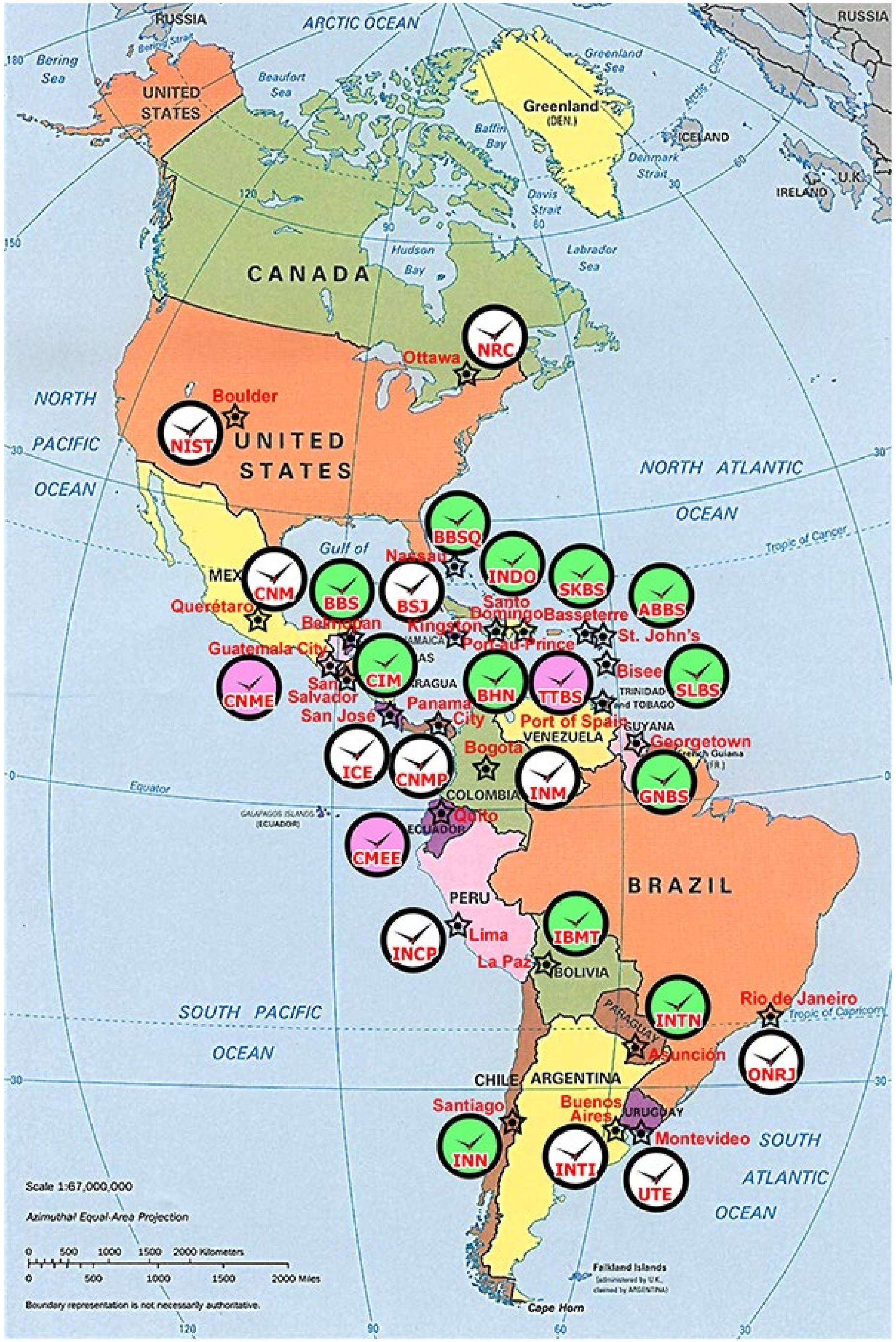
INN
INTI
UTE

Current Status of SIMTN Operation



The SIM Time Network

- ✓ The SIM Time Network is based on real-time common-view GPS comparisons. All participants use identical measurement equipment.
- ✓ SIM measurement systems are installed at 26 laboratories but not all are operational. Laboratories with operational systems continuously compare their clocks to each other, 24 hours per day, 7 days per week.
- ✓ Laboratories that operate one or more cesium clocks and/or hydrogen masers are indicated by the white clocks on the map. The green clocks represent laboratories that operate rubidium clocks that are automatically disciplined to agree with SIMT. The purple clocks represent laboratories that operate either a GPS disciplined clock or an undisciplined rubidium clock.

SIMTN Participants

Lab Acronym	Nation	System Number	Year Shipped	Lab Acronym	Nation	System Number	Year Shipped
NIST	USA	06	2005	TTBS	Trinidad and Tobago	20	2009
CNM	Mexico	07	2005	SLBS	St. Lucia	21	2010
NRC	Canada	08	2005	INN	Chile	22	2010
CNMP	Panama	09	2005	ABBS	Antigua and Barbuda	23	2011
ONRJ	Brazil	10	2006	CMEE	Ecuador	24	2012
ICE	Costa Rica	11	2007	IBMET	Bolivia	25	2012
INM	Colombia	12	2007	SKBS	St. Kitts and Nevis	26	2014
INTI	Argentina	14	2007	GNBS	Guyana	27	2014
CNME	Guatemala	15	2007	CIM	El Salvador	28	2014
BSJ	Jamaica	16	2007	INDO	Dominican Republic	29	2015
UTE	Uruguay	17	2008	BBSQ	Bahamas	30	2016
INTN	Paraguay	18	2008	BHN	Haiti	31	2016
INCP	Peru	19	2009	BBS	Belize	32	2018

Sources of SIMT(*k*), the 1 pps inputs to the SIMTN

Source of SIMT(*k*)	**Number of Labs in group**	**Laboratory Acronyms**
Ensemble time scale including hydrogen masers and cesium clocks	4	CNM, NIST, NRC, ONRJ
Cesium Clock	8	BSJ, CNMP, IBMET, ICE, INM, INTI, INCP, UTE
GPS Disciplined Clock	3	CMEE, CNME, TTBS
Rubidium Clock (disciplined to SIMT)	11	ABBS, BBS, BBSQ, BHN, CIM, GNBS, INDO, INN, INTN, SKNBS, SLBS

Current operational status of SIMTN Systems

Laboratory Acronyms	System Number	Month of last data contribution to SIMTN	Notes
ABBS, CIM, CMEE, CNM, CNME, CNMP, IBMET, ICE, INCP, INDO, INM, INN, INTI, NIST, NRC, ONRJ, UTE	Various	May 2022	These 17 labs have been regular contributors to SIMTN during most of pandemic
TTBS (Trinidad and Tobago)	20	April 2022	Running and trying to upload data, apparent firewall issues
INTN (Paraguay)	18	February 2022	Running and trying to upload data, apparent firewall issues
SLBS (St. Lucia)	21	November 2021	Was a regular contributor until late 2021
BBS (Belize)	32	April 2021	ISP blocking outgoing traffic, BBS is working on it
SKBS (St. Kitts)	26	September 2020	Mold situation in building forced relocation of system
GNBS (Guyana)	27	April 2016	Hardware failure, NIST has offered to repair system if GNBS will send it back, no luck so far
BSJ (Jamaica)	16	July 2012	Many attempts to help BSJ restart system have failed
BHN (Haiti)	31	No data sent so far	Installed GPS antenna in March 2020, no correspondence since
BBSQ (Bahamas)	30	No data sent so far	NIST repaired system in August 2021, still waiting for installation, last email correspondence was today!

SIMTN CPUs and Operating Systems

Windows Operating System	CPU	Number of Labs in group	Laboratory Acronyms
Windows 2000	Pentium III	1	NRC
Windows XP Pro	Pentium III	10	BSJ, CMEE, CNM, GNBS, IBMET, INCP, INN, INTI, NIST, ONRJ
Windows 7	Atom	8	BHN, CIM, CNMP, ICE, INDO, INM, SKBS, UTE
Windows 10	Atom	7	ABBS, BBS, BBSQ, CNME, INTN, SLBS, TTBS

SIM NTP Intercomparison Participants

Lab Acronym	Nation	Month of last participation
CIM	El Salvador	May 2022
CMEE	Ecuador	May 2022
CNM	Mexico	May 2022
CNME	Guatemala	May 2022
CNMP	Panama	May 2022
IBMET	Bolivia	May 2022
ICE	Costa Rica	May 2022
INCP	Peru	**December 2021**
INDO	Dominican Republic	**December 2021**
INM	Colombia	May 2022
INTI	Argentina	May 2022
NIST	USA	May 2022
NRC	Canada	May 2022
ONRJ	Brazil	May 2022
UTE	Uruguay	**February 2022**

SIMTN Participants Contributing to Coordinated Universal Time (UTC)

UTC Participants

Lab Acronym	Nation	UTCr Participant?	On Circular-T before SIMTN?	Link Uncertainty, ns (April 2022)
CNM	Mexico	Y	Y	4.2
CNMP	Panama	Y	Y	5.2
ICE	Costa Rica	Y	N	7.7
INCP	Peru	N	N	20.6
INM	Colombia	N	N	20.1
INTI	Argentina	Y	N	20.0
NIST	USA	Y	Y	2.5
NRC	Canada	Y	Y	3.2
ONRJ	Brazil	Y	Y	20.0
IBMET	Bolivia	In progress		
UTE	Uruguay	In progress		

How the SIMTN Works and System Design Details

The SIM Measurement System - Overview

Simple design made it easy and inexpensive for SIM labs to compare their clocks. It includes:

- ✓ 8-channel GPS receiver (C/A code, L1 band)
- ✓ Time interval counter with 30 ps resolution
- ✓ Rack-mount PC and flat panel display
- ✓ Pinwheel type antenna

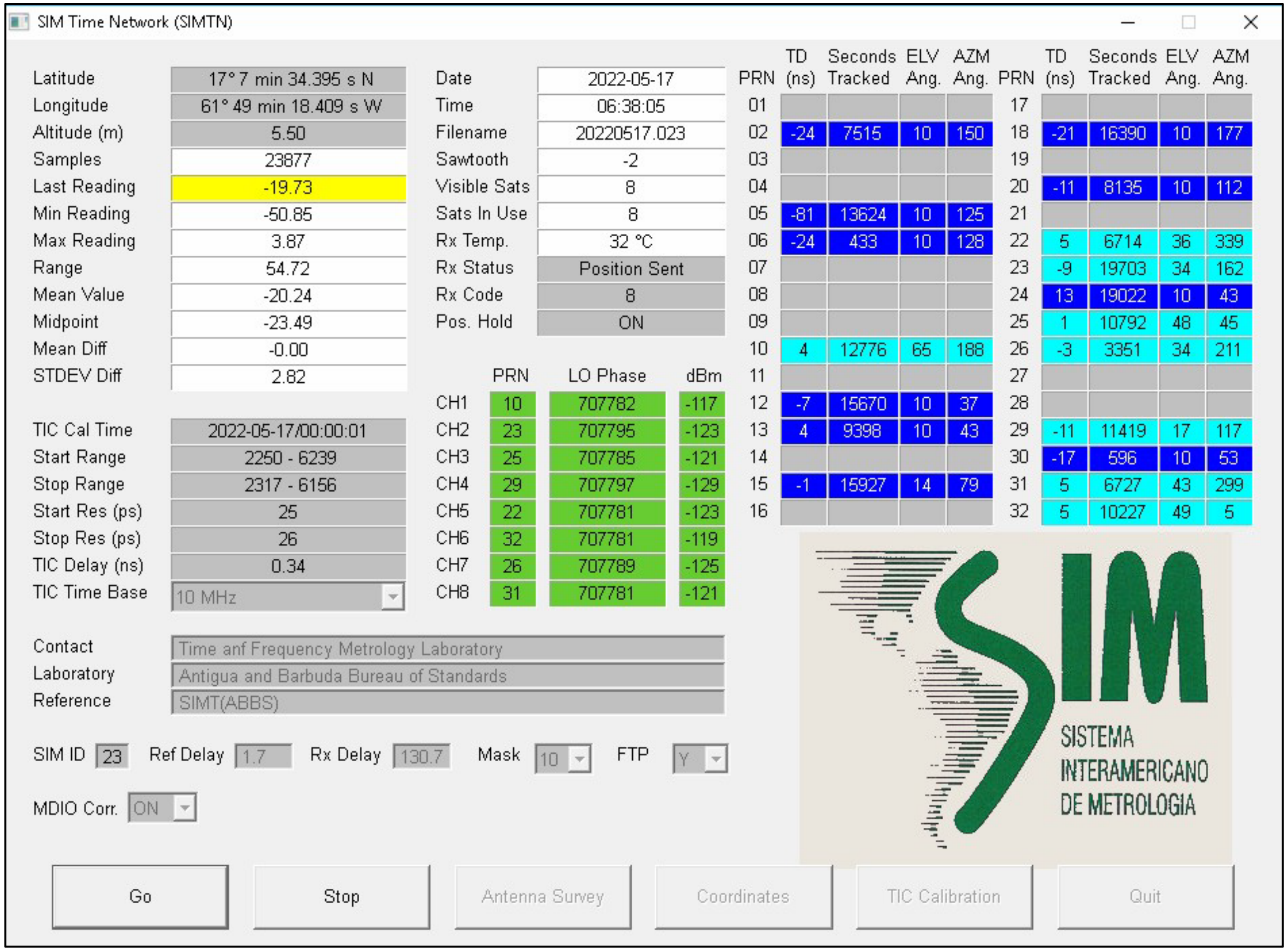
SIM
SISTEMA INTERAMERICANO DE METROLOGÍA

The receiver measures all visible satellites and stores 1-minute and 10-minute averages.

All systems are connected to the Internet, and send their files to three web servers (in Canada, Mexico, and the U. S.) every 10 minutes.

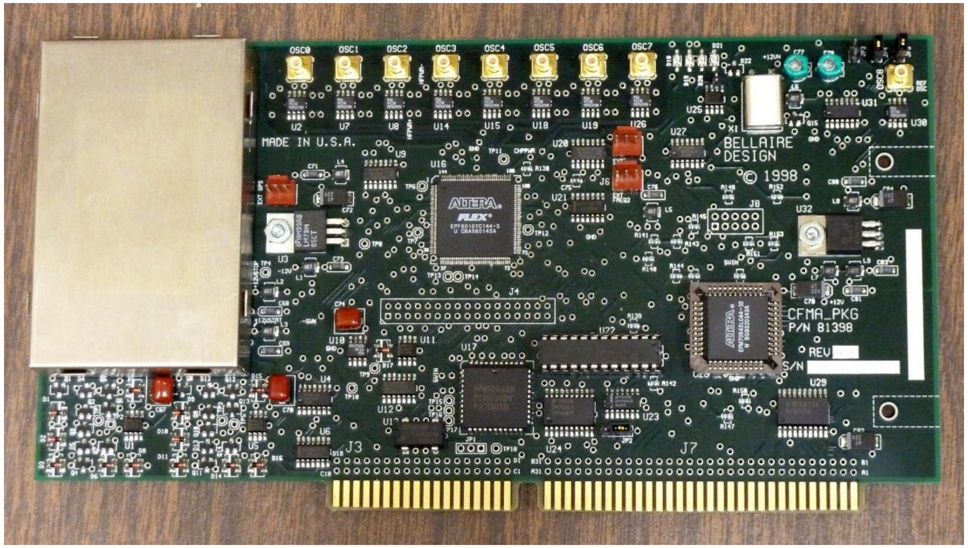
The web server processes data "on the fly" in near real-time. Results can be viewed on the web in either common-view or all-in-view format.

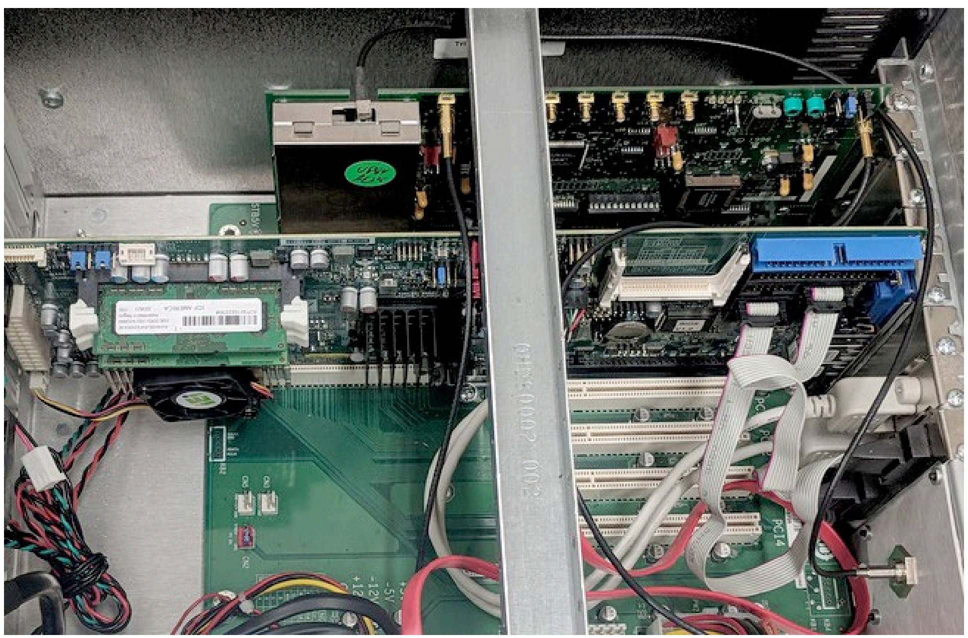
The SIM Measurement System – Basic Functions



- ✓ Basic function of system is to continuously measure and record the time interval between two 1 pps signals.
- ✓ One signal is from the local SIMT(*k*) clock. The other signal is from a calibrated GPS clock. The time offsets from each satellite are extracted and recorded separately.
- ✓ Measurements are made every second but data are stored as 1-minute and 10-minute averages.

The SIM Measurement System – Instrumentation





- ✓ The measurement engine of the SIM system is a time interval counter (TIC) designed for NIST many years ago with an integrated GPS receiver. It plugs into the passive backplane inside the SIM measurement chassis (ISA bus).

- ✓ The TIC is software controlled and the time difference between SIMT(*k*) and GPS is recorded for each satellite.

- ✓ A modelled ionospheric delay correction, using parameters broadcast by GPS, is applied to the GPS – SIMT(*k*) measurements.

The SIM Measurement System – File Formats

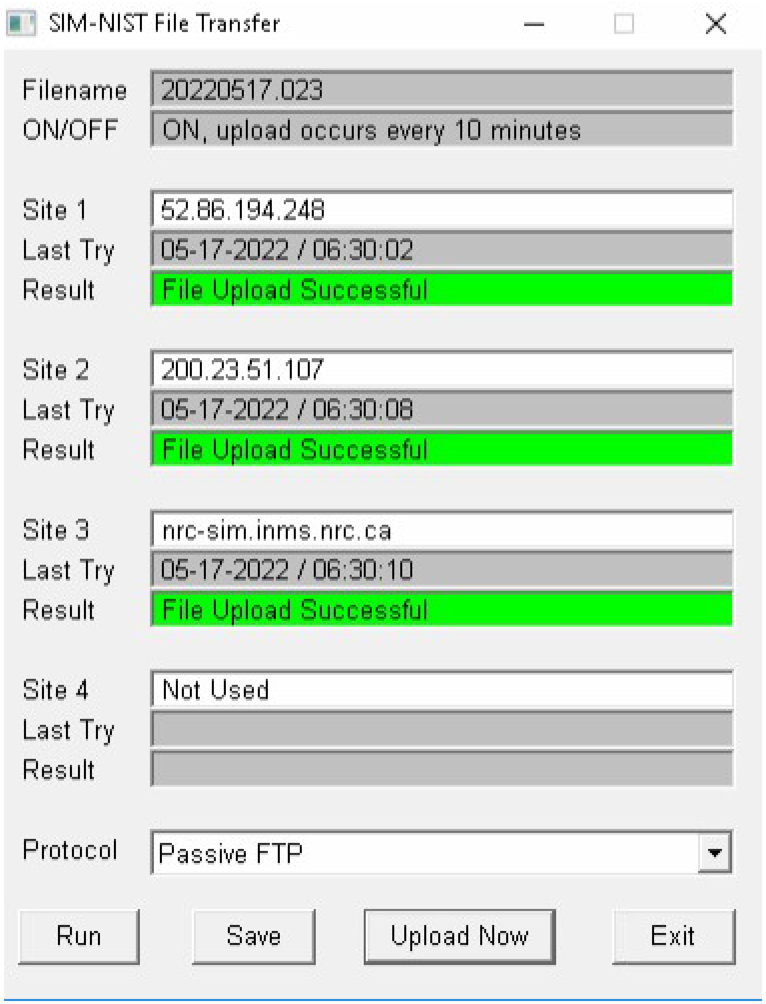
```
2022-05-18
59717
Time and Frequency Division in Boulder
National Institute of Standards and Technology
SIMT(NIST)
1 Hz
CAL Time = 2022-05-18/00:00:01
START Res = 25 ps
STOP Res = 26 ps
TIC Delay = 0.21 ns
REF Delay = 433.4 ns
RX Delay = -8.8 ns
Mask Angle = 10°
TEMP Rx = 28 °C
LAT =  39° 59 min 44.579 s N
LON = 105° 15 min 43.185 s W
ALT = 1646.72 m
0010 - - - - 2.53 - - - - - - - - -1.25 - -.4 - - -.24 - - - - 2.71 - - 8.31 - - -1.61 - - -
0020 - - - - 2.42 - - - - - - - - -1.07 - .92 8.34 - -1.8 - - - - 2.23 - - 9.13 - - -2.28 - - -
0030 - - - - 1.94 - - - - - - - - 1.41 - -.58 11.27 - -1.24 - - - - 1.15 - - 8.96 - - -1.83 - - -
0040 - - - - 1.18 - - - - - - - - -.35 - .5 8.36 - -1.94 - - - - -.2 - - 8.54 - - -1.13 - - -
```

- ✓ Ten-minute averages are uploaded to SIMTN. File gets larger during day, but size does not exceed about 18 kB. Each satellite average is stored on one comma delimited line.

```
PRN STTIME TMP TRKL ELV AZTH     REFGPS
    hhmmss dgC  s   .1dg .1dg     .1ns
 05 000200 28   60  390 0480        25
 13 000200 28   60  370 0870       -13
 15 000200 28   60  480 1390         8
 18 000200 28   60  570 3130        -3
 20 000200 28   60  110 0560         3
 23 000200 28   60  360 2370        16
 26 000200 28   60  190 2860        88
 29 000200 28   60  710 1670       -22
```

- ✓ One-minute averages are stored but not uploaded. Daily file size is about 450 kB. Satellite tracks are stored on individual lines that includes receiver temperature.

The SIM Measurement System – File Transfer



- ✓ At the end of each 10-minute measurement interval, an FTP client sends the file to three servers, maintained by NIST, CENAM, and NRC, respectively.
- ✓ The NIST and NRC servers are now hosted by commercial cloud providers.
- ✓ Successful FTP file transfers require the SIM labs to keep ports 20 and 21 open on their firewalls so that files can be "pushed" out to the servers.

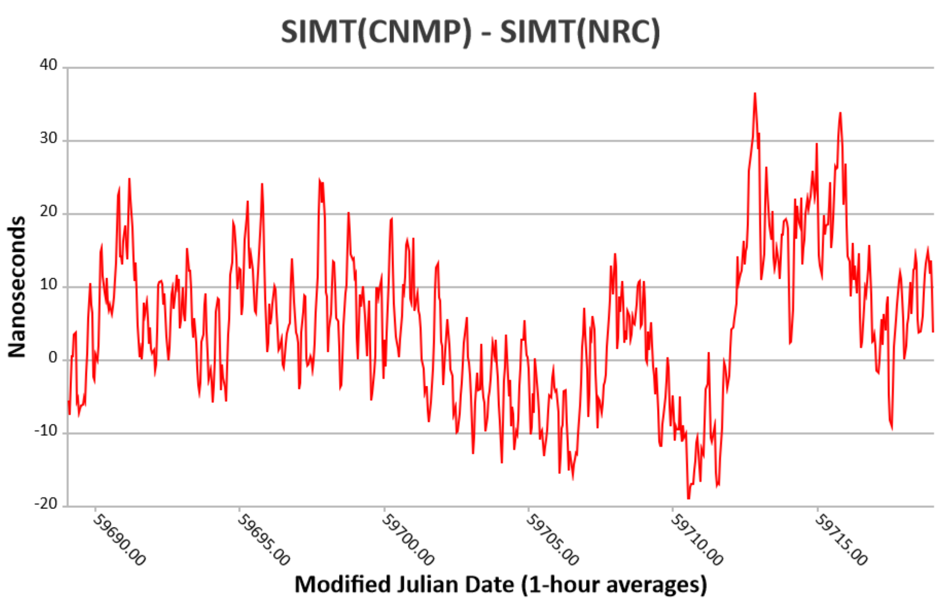
SIMTN Server Side Processing

SIMT(CNMP) versus SIMT(NRC) via Common-View GPS

1 Day Averages 1 Hour Averages 10 Minute Averages Next Date Last Date Flip

Laboratory 1	Centro Nacional de Metrologia de Panama AIP	**ID Number**	009	**End Date**	2022-05-19
Latitude	9° 0 min 3.590 s N	**Counter Delay**	-0.05 ns	**Reference Source**	SIMT(CNMP)
Longitude	79° 35 min 5.880 s W	**REF Delay**	45.66 ns	**Mask Angle**	10°
Altitude	47.23 m	**Receiver Delay**	122.1 ns	**Receiver Temp.**	26 °C
Laboratory 2	National Research Council	**ID Number**	008	**Baseline**	3989.233 km
Latitude	45° 27 min 14.853 s N	**Counter Delay**	0.49 ns	**Reference Source**	SIMT(NRC)
Longitude	75° 37 min 25.777 s W	**REF Delay**	38 ns	**Mask Angle**	10°
Altitude	82.59 m	**Receiver Delay**	229.3 ns	**Receiver Temp.**	34 °C

Hours in Common-View	Mean Time Offset (ns)	Range (ns)	Frequency Offset	Confidence (r)
720	4.80	55.57	$+9.93 \times 10^{-16}$	+0.07



- ✓ All common-view data reduction, data storage, and graphics functions are performed by the three SIM servers.
- ✓ Each server performs identical tasks, enabled by about 20 CGI applications that run when requested by users with a web browser. The CGI apps are 32-bit executables that require the Windows platform to run.

Possible Future Design Enhancements to SIMTN Measurement Systems

Some possible ideas for a next generation SIMTN

IDEA A – Redesign system with geodetic GNSS receiver that outputs RINEX files at 30 second intervals. Convert RINEX files on fly to CGGTTS format.

> **Pros:** SIM systems could directly contribute data to UTC, improved performance, TIC would not be needed.
>
> **Cons:** High cost of geodetic receivers, large amounts of data processing. Realizing any performance gains and contributing to UTC would still require all labs without cesium clocks to obtain cesium clocks. Real-time nature of SIMTN would be completely lost unless all web applications were rewritten.

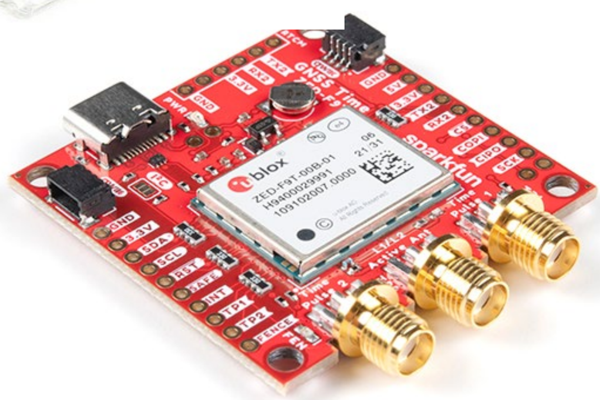
IDEA B – Redesign system with geodetic GNSS receiver that outputs RINEX files at 30 second intervals. Convert RINEX files on fly to existing SIM format.

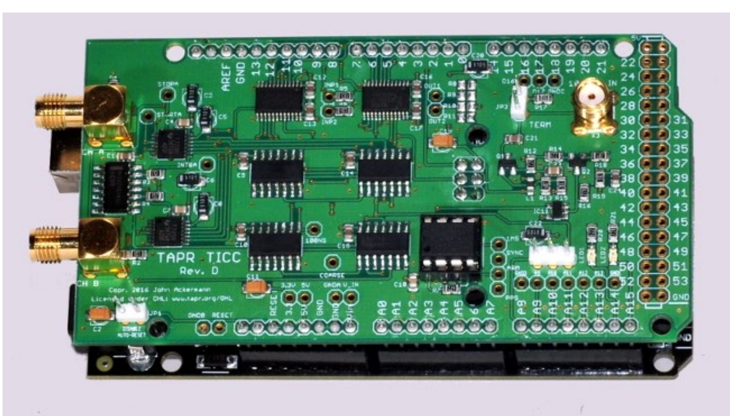
> **Pros:** Real-time nature of SIMTN could be preserved, improved performance, TIC would not be needed. Existing web apps would still work.
>
> **Cons:** High cost of geodetic receivers, large amounts of data processing.

IDEA C – Redesign system with low-cost hardware, interfacing directly to receiver with binary messages (no RINEX) and generate existing SIM format.

> **Pros:** Low-cost multi-frequency receivers can match geodetic receiver performance by cancelling ionospheric affects in real-time (similar to P3 method). Hardware would be cheaper and easier to replace and maintain that existing SIM system. Real-time network would be preserved, and existing web apps would still work.
>
> **Cons:** A separate time transfer system would still be needed by labs that contribute to UTC.

A quick look at “Idea C”





- ✓ Idea C could be implemented with about $600 USD of hardware, plus the cost of a chassis and connectors. For purposes of example, the CPU could be a Raspberry Pi ($100), the TIC the TAPR unit with 60 ns resolution ($200), and the GPS unit a development board based on the multi-constellation, multi-frequency uBlox F9T ($300).

- ✓ Software could be open source, written in Python.

"Idea C" – File Transfer and Server-Side Processing

- ✓ Instead of FTP, each completed track could be "pushed" to the server using an https POST command, or something similar. Assuming that all three SIM servers implemented https (port 443 web access), then the data would be encrypted (rather than clear text) and any existing FTP security and firewall concerns would go away.

- ✓ Each system could have a unique key that was sent to each server as part of the POST command. The servers would parse all the incoming messages and append each new track to the appropriate file.

- ✓ CGI web applications could be rewritten in Python making them no longer tied just to Windows servers. They could simultaneously be converted to 64-bit, as 32-bit web applications will likely eventually be obsolete.

Summary

The SIM Time Network has led to increased cooperation amongst SIM laboratories. It supports local calibrations and measurements throughout the SIM region by producing measurement results in near real-time, and it has inspired numerous SIM NMIs to develop time and frequency laboratories and to contribute to Coordinated Universal Time (UTC). Our future goals should include:

- ✓ Working together to get all 26 SIMTN systems running.
- ✓ Working together to ensure that more SIM NMIs can contribute to UTC.
- ✓ Working together to modernize the SIMTN so that it takes advantage of new technology, so that it can remain maintainable for many years to come, and to improve time transfer performance by reducing measurement noise.