Implementing Galileo/GNSS to GPS Time Offset
Moving Further Towards Interoperability Through "Time"

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USNO Precise Time Authority

Ref: DODD 4650.05 and 4650.07:

The Secretary of the Navy shall, in addition, direct the U.S. Naval Observatory to maintain the standard for uniformity of Precise Time and Time Interval (PTTI) services and the Celestial Reference Frame for DOD components.

Ref: CJCS Master Positioning, Navigation, and Timing Plan:

The U.S. Naval Observatory, is the agency responsible for PTTI reference values for all services, agencies, contractors, and related scientific laboratories, coordinating DoD timing capabilities, analysis, evaluation, and monitoring of R&D and operational PTTI systems.

Ref: "America Competes Act," United States Public Law 110-069, 110th Congress (9 August 2007): **According to the America Competes Act of 2007, Coordinated Universal Time (UTC) is the official time for the United States and the responsibilities for its realization are shared by National Institute of Standards and Technology and U.S. Naval Observatory.**

USNO is the manager and sole source of PTA information for DOD

USNO Master Clock

Washington, DC

National and DoD standard of time: UTC (USNO)

Real-time realization of USNO time scale

Steered to UTC (BIPM)

Ensemble of

- 75 Cesium standards
- 26 Hydrogen masers
- 4 Rubidium Fountain

USNO Alternate Master Clock

Schriever AFB, Colorado Springs, CO

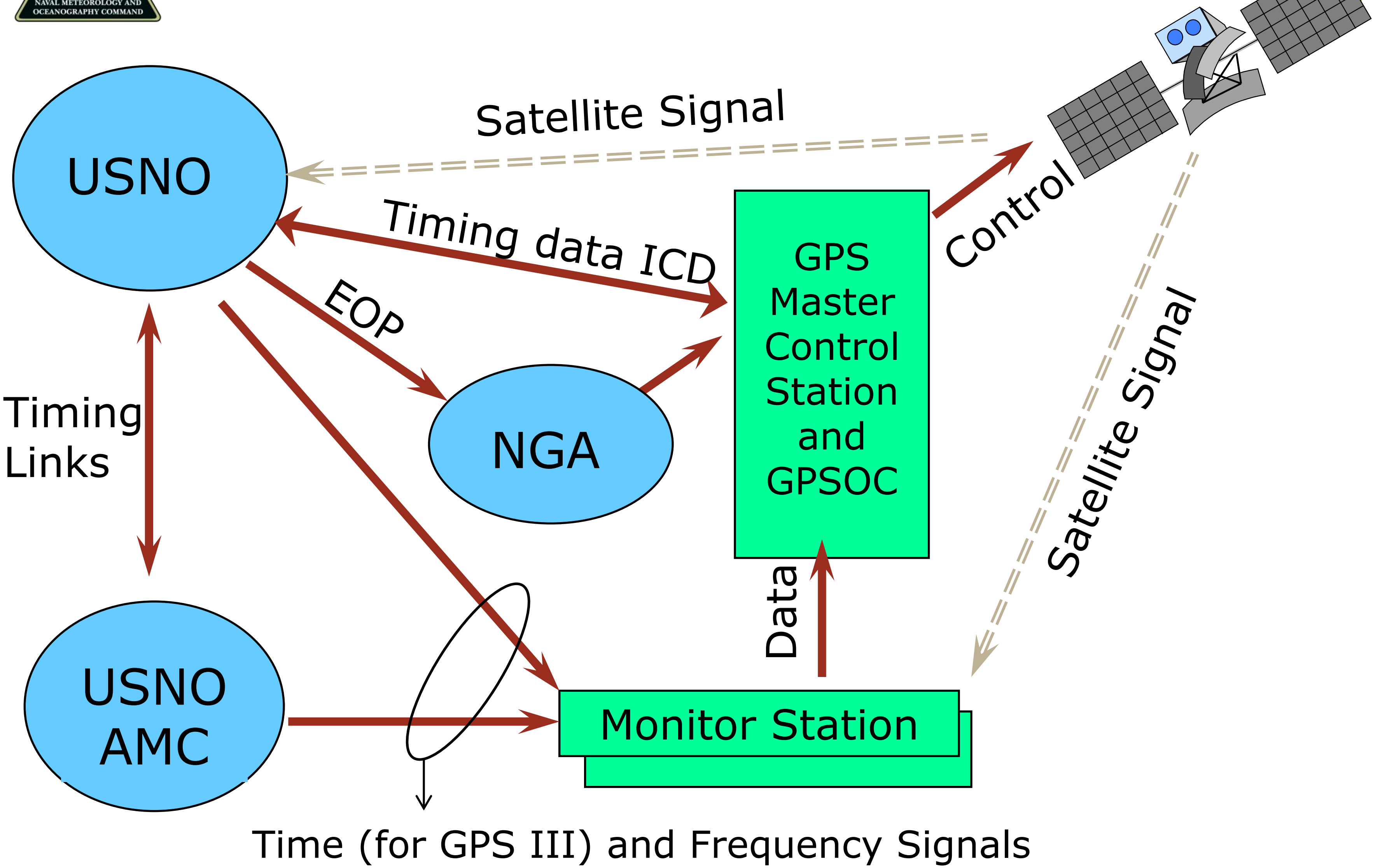
Steered of UTC (USNO) Washington DC

Co-located with USAF 2SOPS & GPS Master Control Station

Ensemble of

- 12 Cesium standards
- 4 Hydrogen Masers
- 1 Rubidium Fountain

USNO Interface to GPS



UTC(USNO) "Time" from GPS

- The UTC broadcast from GPS is referenced to the United States Naval Observatory real-time realization of UTC known as UTC(USNO).
- UTC(USNO) is obtained from GPS time by subtracting an integral number of seconds (leap seconds) and applying the fine UTC correction information contained in the GPS broadcast navigation data (sub-frame 4 page 22).
- USNO provides data to GPS control segment through a special interface documented in "GPS-ICD-202E"
  - This interface has been in place for over 30 years servicing all critical timing user communities.
- *"New" USNO and GPS are teaming to coordinate GPS time with that of other GNSS systems, resulting in the broadcast of a GPS to GNSS Time Offset (GGTO) message.*

GPS TO GNSS TIME OFFSET
GGTO

Global Navigation Satellite System (GNSS) and related augmentation systems

- The US Government operated the Global Positioning System (GPS) (fully operational for almost 20 years)
  - Wide Area Augmentation System (WAAS)

- The Russian Federation operated Global Orbiting Navigation Satellite System (GLONASS) or *"Global'naya Navigatsionnaya Sputnikovaya Sistema Global Navigation Satellite System"* (now at full operational capability)
  - SDCN will be the Russian SBAS service

- The European Union Galileo system (four production satellites launched over the past two year, undergoing validation phase, IOC 2015)
  - EGNOS which augments GPS like WAAS

- China (BeiDou Navigation Satellite System (BDS) "Compass" 15 satellites already in orbit (5 GEO, 5 IGSO, 5 MEO satellites, FOC 2020)

Other regional GNSS Systems

- The Japanese Government Quazi-Zenth Satellite System (QZSS) (First satellite launch was in Summer of 2010, approved for more 2018)
  - MSAS which augments GPS
- India - Indian Regional Navigation system (IRNSS) (First satellite launch in June 2013, six more over the coming years)
  - GAGAN (GPS And Geo Augmented Navigation)

Future GNSS Infrastructure

From: John Betz: Mitre

US-EU Agreement on GGTO

U.S. Secretary of State Colin Powell, European Commission Vice-President Loyola de Palacio, and Irish Foreign Minister Brian Cowen signed the Agreement on the Promotion, Provision, and Use of Galileo and GPS Satellite-Based Navigation Systems and Related Applications. June 2004

The Parties also agree that GPS and GALILEO shall be, to the greatest extent possible, interoperable at the non-military user level. [...] The Parties also agree to transmit the time offsets between GALILEO and GPS system times in the navigation messages of their respective services, as outlined in the document entitled "GPS/GALILEO Time Offset Preliminary Interface Definition"

GPS and Galileo intend to determine, coordinate and broadcast GGTO following the Preliminary Interface Definition elaborated by GGTO sub-group of WG-A.

GNSS Compatibility and Interoperability

- Compatibility refers to the ability of global and regional navigation satellite systems and augmentations to be used separately or together without causing unacceptable interference and/or other harm to an individual system and/or service should be encouraged.

Do no Harm

- Interoperability refers to the ability of global and regional navigation satellite systems and augmentations and the services they provide to be used together to provide better capabilities at the user level than would be achieved by relying solely on the open signals of one system.

Combine

Interoperability of GNSS

- Navigation users can potentially benefit from multiple GNSS constellations.
  - Resulting in 2X or 3X the number of usable SVs improving satellite visibility and/or reducing DOP in challenging environments.
- In 2004 GPS and Galileo agreed to develop and jointly broadcast GPS-to-Galileo Time Offset (GGTO)
  - GPS and USNO agreed to a development plan with USNO assigned the role of estimating the GGTO for GPS and coordination of GGTO with other systems.

GNSS Timekeeping Function

Navigation Service
Where am I

Twofold:

- Navigation Timekeeping:
  critical for navigation mission, needed for orbit determination/ prediction and internal satellite clock synchronization, not intended for timing applications.

- Metrological Timekeeping:
  not critical for navigation, but needed to provide a UTC timing services (time dissemination) to support communication systems, banking, power grid management, etc…

Timing Service
UTC/PTTI

GPS Time and Navigation

- Each GPS satellite carries Atomic clocks that are precisely synchronized to a common time scale "GPS Time"
- GPS Time is kept in closet alignment with UTC(USNO), typically within 10 nanoseconds
- Each GPS satellite also broadcasts its precise position in space (typically better than one meter)
- A GPS user receiver records the time difference between the receiver clock and the transmitted satellite clock, which provides a measure of distance between the user and the satellite
- These time difference measurements used with knowledge of the satellites position allows the user to solve for its unknown position and time.
- Four satellites are required to compute the four dimensions of user X, Y, Z (position) and User Receiver Time.

Two main methods to deal with GNSS time scales differences

- User solves for the error: It is expected that the most accurate way to account for these navigation time scale biases would be to solve for this error as a fifth (or sixth) unknown within each user receiver. (99 % solution)

- GNSS system provides a broadcast correction: The GGTO will be estimated by the GNSS and broadcast as an additional parameter in GNSS navigation messages. (1 % solution)
  GGTO

Other GNSS

Combined GNSS Navigation Solution

- Other GNSS systems like GLONASS and Galileo operate very similar to GPS with each system maintaining its own independent navigation time scale.
- Most GNSS systems have agreed to the principle of aligning their systems navigation time scales to their local representation of UTC (modulo-one second).
- GPS and Galileo have agreed to keep their navigation time scales to within 50 nanosecond of their local representations of UTC
- But even this small 50 nanosecond timing bias leads to several meters of position error, when a user attempts to combine its system with a second GNSS system to form a combined navigation solution.
- For interoperability between GNSS systems this time scale difference should be less than < 5 ns

GGTO Interface Performance Requirements

GGTO validity

The validity period of the GGTO shall be minimum 24 consecutive hours

GGTO offset accuracy

The accuracy of the offset between GST and GPS Time (modulo 1 s)

shall be less than 5 ns with 2-sigma confidence level over any 24 hours.

GGTO Stability

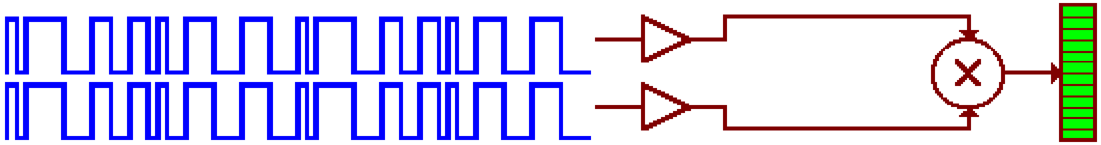
The stability of the GGTO, expressed as an Allan deviation, shall be better than 8x10e-14 over any one day.

GPS ICD-200 Message Type (first published in 2004) the GNSS to GPS time offset

Table 30-IX. GPS/Galileo Time Offset Parameters

Parameter		No. of Bits**	Scale Factor (LSB)	Effective Range***	Units
A_{0GGTO}	Bias coefficient of GPS time scale relative to GNSS time scale	16*	2^{-35}	602,112	Seconds
A_{1GGTO}	Drift coefficient of GPS time scale relative to GNSS time scale	12*	2^{-51}		sec/sec
A_{2GGTO}	Drift rate correction coefficient of GPS time scale relative of GNSS time scale	6*	TBD		sec/sec^2
t_{otGGTO}	Time data reference Time of Week	14	TBD		Seconds
WN_{otGGTO}	Time data reference Week Number	13	2^0		Weeks
GNSS	GNSS system indicator	3			

* Parameters so indicated shall be two's complement with the sign bit (+ or -) occupying the MSB;
** See Figure 30-10 for complete bit allocation;
*** Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.



Thank You

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