**SYSTEM ENGINEERING AREA**

**Time Management Working Group Charter**

**May 2019**

**Approved:**

**Jon Hamkins\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

### BoF Chair Date

### Peter Shames\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

### Area Director Date

### Leadership

Proposed chair: Jon Hamkins

Proposed deputy chair: TBD

### Scope of activity

The Time Management Working Group will concentrate on creating and maintaining standards relating to time transfer, time correlation, and time synchronization in space operations contexts. The activities will be coordinated under the Systems Engineering Area (SEA).

### Rationale for activity

Space agencies need to manage time on their spacecraft for the effective execution of maneuvers, coordination of scientific observations, docking or other robotic collaboration, and for scheduling of communications links or other activities. CCSDS member agencies see value in standardizing parameters and protocols for accomplishing time correlation and synchronization, so that agencies can offer cross support for their timing needs. The biggest motivation for doing this work in CCSDS is to enable a move from mission or agency approaches to internationally interoperable standardized approaches.

### Goals

Standards shall be developed to promote common understanding of time correlation and synchronization approaches and to facilitate cross support of time management operations among space operations assets. The Working Group has the following goals:

1. Collect and analyze the technical literature, and codify it into specific time correlation and synchronization methods that can be analyzed and compared, in preparation for developing CCSDS Green, Blue, and Magenta Books. As part of this, the requirements for time correlation and synchronization for emerging mission domains/enterprises will be determined and reviewed with other CCSDS stakeholders.
2. Produce a Green Book describing suitable operational domains, applications, and methods used for time correlation and synchronization. The Green Book will identify requirements for interoperable time correlation and time synchronization services. Applications that may make use of time correlation and/or synchronization include maneuvers, coordination of scientific observations, one-way ranging, docking or other robotic collaboration, and scheduling of communications links or other activities. The book will describe methods for time correlation and synchronization, including those for near Earth, cislunar, and deep space regimes. The book will separately address application domains in which a Global Navigation Satellite Service (GNSS) is or is not available. A multitude of time transfer and synchronization methods will be described, using correlation techniques such as existing CCSDS ranging methods, one way data delay coupled with trajectory data, two-way range signaling similar to that used by the Tracking and Data Relay Satellite System (TDRSS)), the use of local area time zones (e.g., rovers and orbiters around Mars), and methods using or not using explicit time code format representations in the signaling. The Green Book will also discuss the roles of clocks, frequency standards, and topics such as X-Ray Pulsars as frequency sources for timekeeping. Error sources will be identified, including limitations in orbit knowledge, calibration, and time tags.
3. Produce one or more Blue Book describing protocols for time correlation and for time synchronization. The Blue Book(s) will define the signaling of time correlation data (signaling containing time code formats) or use of other suitable signals such as telemetry/PN/GMSK+PN ranging needed to accomplish time correlation. They will define protocols for time synchronization that are suitable for use in traditional single space link deployments as well as in Solar System Internet (SSI) deployments using DTN or IP protocols.
4. Produce a Magenta Book that defines recommended procedures for using these normative approaches, in space and on the ground, to produce the desired outcomes for cross supported mission and multi-mission time management.

### Survey of similar standards efforts undertaken in other bodies and elsewhere in CCSDS

CCSDS has developed standards for Time Code Formats (CCSDS 301.0-B-4), Pseudo-Noise (PN) Ranging Systems (CCSDS 414.1-B-2), GMSK+PN Ranging, and is in the process of developing a standard for telemetry ranging (to be included in CCSDS 401.0-B-30), PN ranging using CDMA from a Relay Satellite (CCSDS 415.1-B-1), Earth Receive Time (ERT) time stamps delivered by Space Link Extension (SLE) return frame services (CCSDS 911.1-B-4, CCSDS 911.2-B-3). Each of these standards relates to the representation of or exchange of time, or the measurement of elapsed time useful in determining the range between a reference point on the ground and a reference point on a spacecraft.

A series of IETF RFCs (RFCs 778, 781, 956, 958, 1059, 1305, 5905, 7822) describes the Network Time Protocol (NTP) and its extensions, for time synchronization over the Internet. NTP is one of the oldest Internet protocols in current use. There is not yet a corresponding set of time synchronization standards for the Delay Tolerant Network (DTN) suite.

There are time and position services from GPS/GNSS that are in wide use for near Earth and that have a usable service volume that may extend to cis-Lunar distances. There is an European Cooperation for Space Standardization (ECSS) clock correlation standard that is used in Europe, and there are other agency and mission clock correrlation approaches, some of which are well documented.

This is not intended to be a comprehensive list, but NIST maintains an atomic clock standard, and has established standard definitions for much of the terminology involved. BIPM also maintains an atomic clock standard and uses the same standard definitions. There are a few terrestrial deployments of synchronized clocks that may be used for timekeeping on Earth, but, aside from GNSS systems, no such “fabric” is deployed in space.

These various standards and standard definitions will be utilized where they are suitable in formulating a time transfer and time correlation protocol, and time synchronization standards. In formulating this approach we will study and utilize, as possible, standards efforts and related reports from other international and national organizations.

### Patent licensing applicability for future standards

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|  | The current WG participants know of no limitations at this stage on usage of the planned technologies as far as patent restrictions or licensing requirements are concerned. Certain GPS localization technologies may be patented and require a license. |

### Technical risk mitigation strategy

No technical risks have been identified by the BOF at this stage.

There are several systems that already support parts of the desired features in specific environments. The Space Network (SN) has deployed transponders that successfully use PN ranging since 1985. GPS and other GNSS systems, for Earth surface and near Earth uses, provide highly accurate time and position information that is globally used.

The following is one example of recent activities that provide some technical risk mitigation. JPL has been testing telemetry ranging and PN ranging and the next generation transponder has accepted the requirement to time tag their clock in association with a specified bit in the PN.

The WG will review and evaluate existing approaches to determine where, and if, they are applicable in the space operations domain.

The WG will define a consistent set of terms that align with best current practices, see annex for definitions of the terms used in this Charter.

### Management risk mitigation strategy

Schedule relies upon the support of multiple CCSDS Agencies and on the allocation of adequate Agency resources to the WG.

This work involves coordination between the Systems Engineering Area (SEA) and the Space Link Services (SLS) and Space Internetworking Services (SIS) areas which develop specific link and internetworking protcols used in time exchange. This will be particularly important for IP and DTN “wide area” deployment in the Solar System Internet. Coordination will also be required between this WG and the Mission Operations and Information Management (MOIMS) SM&C & Nav WGs for requirements and as stakeholders when they work on MO Time Services and Nav data exchange standards. Coordination will also be required between this WG and the Spacecraft Onboard Information Services (SOIS) App WG when they work on electronic data sheets for onboard clocks to provide time access services for MO Time Services and for other applications. Security topics, if there are any, will be reviewed with the SEA Sec WG when and as required.

A risk management approach will be used to formulate a risk management plan and identify risks other than schedule and resources.

### Schedule

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| **Date** | **Milestone** |
| May 2019 (Spring meeting) | BoF conclusion to AD and WG charter submitted to SE Area |
| 1st July 2019 | WG Charter Adopted by CESG and CMC |
| 1st July 2019 | Green Book organization prepared and work delegated |
| 15 September 2019 | First Draft of the Green Book before the fall meeting 2019 (ambitious) |
| October 2019 | First Draft Deadline for comments |
| November 2019 | White Book(s) on standard approaches for time correlation and synchronization protocols based for various operational environments. (Blue Book track) |
| August 2020 | Second draft of the Green Book (before the fall meeting of 2020) |
| November 2020 | Final Green Book after the fall meeting 2020 (18 months) |
| November 2020 | Final standard White Book submitted to AD for further processing |
| September 2021 | White Book on recommended practices for deployments using these normative approaches, in space and on the ground. (Magenta Book track) |
| September 2021 | Blue Book(s) prototyped |
| March 2022 | Blue Book(s) published |
| November 2022 | Final recommended practice White Book submitted to AD for further processing |
| March 2023 | Magenta Book published |
| June 2023 | WG disbands |

**Annex – Definition of terms**

* **Accuracy** - The degree of conformity of a measured or calculated value to its definition, related to the offset from an ideal value. [3]
* **Clock** - a device that generates periodic, accurately spaced signals for timekeeping applications. A clock consists of at least three parts: an oscillator, a device that counts the oscillations and converts them to units of time interval (such as seconds, minutes, hours, and days), and a means of displaying or recording the results. Spacecraft clocks are subject to inaccuracies due to oscillator imperfections, clock rate, thermal conditions, proton flux, power flux, relativistic effects. [3]
* **Clock-Ensemble** - A clock-ensemble is a group of two or more, possibly dissimilar, clocks whose time scales are algorithmically combined to produce a stable and robust time and frequency reference system.
* **Coordinated Universal Time** (UTC) - The international atomic time scale that serves as the basis for timekeeping for most of the world. UTC is a 24-hour timekeeping system. The hours, minutes, and seconds expressed by UTC represent the time-of-day at the Earth's prime meridian (0° longitude) located near Greenwich, England. [3]
* **Global Navigation Satellite Systems** (GNSS) - A satellite system that can be used to locate a user’s receiver anywhere in the world.  The Global Positioning System (GPS) was the first global navigation satellite system (GNSS), but has been followed by the three other systems, BeiDou, Galileo, and GLONASS. [3]
* **Gravitational Time Delay** – The physical effect that increases transit time and imparts a Doppler Shift to a signal passing near a massive object; e.g., when radar and radio beams pass closer to the Sun. Activities such as cross-solar system time synchronizations or distance determinations using ranging data must correct for this effect. [4]
* **International Atomic Time** (TAI) - A time scale maintained internally by the BIPM, but seldom used by the general public. TAI realizes the SI second as closely as possible, and runs at the same frequency as Coordinated Universal Time (UTC). However, TAI differs from UTC by an integral number of seconds. This difference is related to leap seconds, and increases whenever a leap second occurs. [3]
* **Mission domain** - The spatial domain in which a mission operates. In this context, the domain defines the available time distribution and dissemination infrastructure. Missions may transit multiple domains during launch, orbital transfer, orbital insertion, and landing.
* **Navigation** - The ability to determine current and desired position—relative or absolute—and apply corrections to course, orientation, and speed to attain a desired position. [4]
* **Precision** - Refers to the degree of mutual agreement among a series of individual measurements, values, or results. In this case, precision is analogous to standard deviation. Precision might also be used to refer to the ability of a device to produce, repeatedly and without adjustments, the same value or result, given the same input conditions and operating in the same environment. This use of precision makes it analogous to repeatability, reproducibility, or even stability. [3]
* **Resolution** - The degree to which a measurement can be determined. For example, if a time interval counter has a resolution of 10 ns, it can produce a reading of 3340 ns or 3350 ns, but not a reading of 3345 ns. This is because 10 ns is the smallest significant difference that the instrument can measure. Any finer measurement would require more resolution. The specification for an instrument usually lists the resolution of a single measurement, sometimes called the single shot resolution. It is often possible to improve upon the single shot resolution by averaging, but resolution can limit the uncertainty of a measurement. [3]
* **Time** – The designation of an instant on a selected time scale, used in the sense of time of day; or the interval between two events or the duration of an event, used in the sense of time interval. [3]
* **Time correlation** - the determination of the variance and time offset of two continuous timescales provided by two different clock-ensembles. This procedure may require the knowledge of clock parameters (stability, drift,...) and also propagation delay of the time transfer. Time correlation allows onboard events, telemetry, commanding activities to be scheduled or interpreted in relation to a common time scale.
* **Time interval** - The elapsed time between two events. In time and frequency metrology, time interval is usually measured in small fractions of a second, such as milliseconds, microseconds, or nanoseconds. [3]
* **Time scale** - An agreed upon system for keeping time. All time scales use a frequency source to define the length of the second, which is the standard unit of time interval. Seconds are then counted to measure longer units of time interval, such as minutes, hours, and days. Modern time scales such as UTC define the second based on an atomic property of the cesium atom, and thus standard seconds are produced by cesium oscillators. Earlier time scales (including earlier versions of Universal Time) were based on astronomical observations that measured the frequency of the Earth's rotation. [3]

**Time synchronization (TS)** - the process of setting a clock-ensemble to the same time. Also the process of setting two or more distributed clock-ensembles to the same time.

1.       TS assumes a network communication model.

2.       TS assumes disparate clocks are inherently inaccurate.

3.       TS assumes minimal clock capability is that of a crystal oscillator (CXO)

4.       TS assumes that communication is discontinuous and communication paths are diverse

5.       TS assumes that timing devices at each end of the communication pipe may be moving

6.       TS assumes that communications transfer functions are subject to relativistic effects

a.       Light travel time

b.       Shapiro effect

c.       Time dilation due to gravitational potential

* **Time transfer** - A measurement technique used to send a reference time or frequency from a source to a remote location. Time transfer involves the transmission of an on-time marker or a time code. The most common time transfer techniques are one-way, common-view, and two-way time transfer. [3]
* **Time unit** – the reference time unit is a second, which is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom. [1], [2].

[1] The International System of Units (SI), NIST Special Publication 330.

[2] <https://www.bipm.org/en/bipm-services/timescales/tai.html>

[3] NIST Time and Frequency Services, <https://www.nist.gov/pml/time-and-frequency-division/popular-links/time-frequency-z/time-and-frequency-z-z-index>

[4] NASA Architecture for Solar System Time Synchronization and Dissemination: Concept of Operations, SpaceOps 2008 Conference, AIAA 2008-3229,<https://arc.aiaa.org/doi/10.2514/6.2008-3229>