CCSDS Navigation Working Group Assistance with LunaNet PNT Services

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**References:**

<https://www.nasa.gov/directorates/somd/space-communications-navigation-program/lunanet-interoperability-specification/#_blank>

1. *LunaNet Interoperability Specification Version 5 Draft*
2. *LunaNet Signal-In-Space Recommended Standard – Augmented Forward Signal (AD1) Version 1 Draft*

**Purpose:**

Leadership of the Consultative Committee for Space Data Standards (CCSDS) identified interest in the LunaNet Interoperability Standard (LNIS), particularly focused on the applicability of current or future CCSDS standards to LunaNet. This paper addresses specific areas in which the CCSDS Navigation Working Group (Nav WG) may elect to support LNIS development and testing.

**Introduction:**

**CCSDS Nav WG**

* The CCSDS Nav WG currently limits its scope to developing standards for file-based transfer of information via terrestrial means.
* Global Navigation Satellite Systems (GNSS) established the Receiver Independent Exchange (RINEX) message structure to exchange GNSS content via files. Thus, no need exists for an additional CCSDS standard.
* In addition, CCSDS WGs outside of the Nav WG have been historically tasked with defining standards for signals to enable ranging observations from either terrestrial stations or space relays. However, efforts have not included defining the associated signal structure nor information content that enables use of the observations (range, Doppler, and angles) by the user to estimate position, velocity, or time.
* Lastly, defining the canon(s) for foundational elements such as reference time systems and reference geodetic systems falls within the responsibilities of other international organizations, such as the International Astronomical Union (IAU). The [CCSDS Green Book 500.0-G-4, Navigation Data – Definitions and Conventions](https://public.ccsds.org/Pubs/500x0g4.pdf) defines the applicability of these internationally recommended canons to the standards developed by CCSDS.

**LunaNet/LNIS**

* LunaNet is a framework for four types of interoperable services based on standards: Communications; Position, Navigation, and Timing; Detection; and Science.
* The concept is to ensure that a system of systems can work together to provide these services though mutually-agreed interoperability definitions, known as the LunaNet Interoperability Specification (LNIS).
* References [1] and [2] represent the current state within the agile development approach laid out for LNIS. [NOTE: As of 5 April 2024, the LNIS WGs completed dispositioning the public comments received on the draft versions and continue to incorporate clarity and further definition in the documents for finalizing this round of updates to the LNIS.]
* Besides AD1 (Reference [2]), Reference [1] identifies the following additional Applicable Documents:
	+ AD2 LunaNet Measurement Schema and Parameters
	+ AD3 LunaNet Detailed Message Definition Document
	+ AD4 LunaNet Location Services for Users
	+ AD5 Lunar Reference System and Lunar Time System Standard
	+ AD7 LunaNet LunaSAR Definition Document
	+ AD8 LunaNet Interoperability Security Specifications
* LunaNet includes definition of services and Direct With Earth (DWE), and proximity and crosslink interfaces in the lunar service volume.
* Some of the DWE interfaces specified in Ref [1] identify CCSDS standards applicable to PNT services, such as [CCSDS 414.1-B-3](https://public.ccsds.org/Pubs/414x1b3.pdf).
* However, a substantial subset of proximity interfaces and associated messages focus on new signal definitions and data exchange between space-to-space assets, and, as such, require a streamlined approach to information transfer. These proximity interfaces fall into two categories: Broadcast (non-scheduled, ubiquitous) and Peer-to-Peer (scheduled, dedicated between one provider and one user) (P2P).
* The Augmented Forward Signal (AFS) defines a broadcast capability primarily focused on PNT via radio navigation, in an analogous manner to GNSS, but with higher data rates to accommodate the additional message-based information content needed to support the lunar environment user scenarios. The data frame structure and message content seeks to replicate that of GNSS to the extent possible, yet must be tailored, expanded and optimized to lunar environment use cases. For example, AFS allows for asynchronous alert messages, coordinate frame transforms, and network access information.
* P2P signals may offer higher data rates than AFS, yet are still subject to space-to-space constraints (e.g. power levels, bandwidth). A “PNT over comm” concept applies to these P2P-based interfaces to enable PNT observables and/or higher rate data content needed for PNT (e.g. an updated Digital Elevation Map for a given sector).

Thus, the LunaNet PNT services combine definitions of a set of signal structures and parameters (channel, modulations, coding and chip rates, identifying codes to achieve specific properties for CDMA, signal level, etc) for use by receivers of the signals as well as messages suitable for space-to-space links and in-situ autonomous operations.

This paper seeks to identify areas of overlap in scope and approach where the CCSDS Nav WG may be able to fruitfully engage to further LNIS development These fall into three categories: Messages, Discrete Parameters for Applicable CCSDS Communication Standards, and Interoperability Testing.

**Messages:**

Messages are essential to enable the different LunaNet services, by conveying necessary information to users. These messages must be suitable for space-to-space link exchanges, optimizing information versus size, standardizing common message elements, and incorporating agility in data content, cadence, and applicability. Message developments where Nav WG support could be suitable include:

1. Observations
	1. Similar to the TDM (CCSDS 503 standard), messages ought to enable information exchange amongst participants for conveying different PNT observables.
	2. Messages should be concise and suitable to enable in-situ navigation onboard participant systems.
	3. Observations may be from, but are not limited to, radio navigation systems based on DWE links, proximity links, crosslinks between provider nodes, or other sensors such as Inertial Measurement Units, cameras, or altimeters.
2. Conjunction Data Message
	1. A concise, yet comprehensive CDM, suitable for space-to-space link exchanges, is sought.
	2. Representations and parameters (e.g. Time Scale for TCA, reference frame) must be optimized for the lunar environment.
3. Ephemeris Representation
	1. Accurate and low weight (information bits) ephemerides are required for enabling in-situ PNT services and for contact coverage planning. For example, observations may only inform a Position, Velocity, and Time (PVT) solution if the participant PVT is known to a certain accuracy. In addition, representations must maintain accurate representation of the state over a specified period of propagation time.
	2. The representation must be able to properly identify a variety of orbit types such as elliptical, Lagrange, and circular, different altitudes, and appropriate modeling of the Moon or the multi-body environment.
	3. General ephemerides, akin to GNSS almanacs are also low weight and required to enable establishing service for extended periods of time.
	4. Nav WG efforts to support LunaNet ephemeris message specifications could include existing analysis from members, discussions on optimal approaches, and issuing subsequent recommendations.
4. Identification of missing Message topics and description of content.
	1. What additional message content may be needed for environments when Earth is not in the operations loop?
	2. What additional messages may be needed for in-situ PNT operations?

**Signal Definition Considering PNT Parameters:**

Although currently outside the purview of the Nav WG. There is a need to identify applicability of CCSDS 414 standard, 415 standard, and/or frame ranging (e.g. telecommand (toward user) or telemetry (from user) ranging over RF or optical links) for in-situ metric tracking observables including Time Transfer. Such standards would likely require adaptations and/or customization to include:

1. Identification of center frequency, PN code and chipping rate combinations conducive to enabling time transfer, in addition to range (or pseudorange) and Doppler observables.
2. Channelization within the wider frequency band allocations.
3. Identification of suitable instantiation(s) with well-defined link parameter definitions, such as data modulation, data rate, modulation indices and power sharing, data and PN shaping, frequency, chip rate, etc.
4. Scenarios include (1) observables derived from two-way (i.e. bi-directional) links, and (2) observables derived from one-way (i.e. unidirectional) links.

**Interoperability Test Plans:**

CCSDS Nav WG experience on developing test plans could be leveraged to generate a set of recommended Test Plans for verifying the interoperability of Interfaces for Services offered by an overall System comprised of individual Position, Navigation, Timing Systems.