LunaNet Signal-In-Space Recommended Standard - Augmented Forward Signal (LSIS)

Draft Version 1

Noted as Applicable Document 1 [AD1] in LNIS V5

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1. INTRODUCTION

This document forms part of the LunaNet Interoperability Specification (LNIS) and describes the characteristics of the signals and messages to support, at the minimum, the PNT services defined in the LNIS. The current version is provided as draft and covers the specifications to ensure interoperability among LunaNet Service Providers (LNSP) supporting the Lunar Augmented Navigation System (LANS). As defined in LNIS, LANS is a service from multiple provider nodes to multiple users at the same time, using a concept similar to Global Navigation Satellite Systems (GNSS). This service is to be provided in 2483.5-2500MHz band via the Augmented Forward Signal (AFS).

Figure 1 outlines the Position, Navigation, and Timing (PNT) services. LANS is shown on the right, and PNT from Point-to-Point (P2P) communication signals is shown on the left. Future versions of recommended standards will include specifications for the other signals and messages required to implement the P2P PNT services.

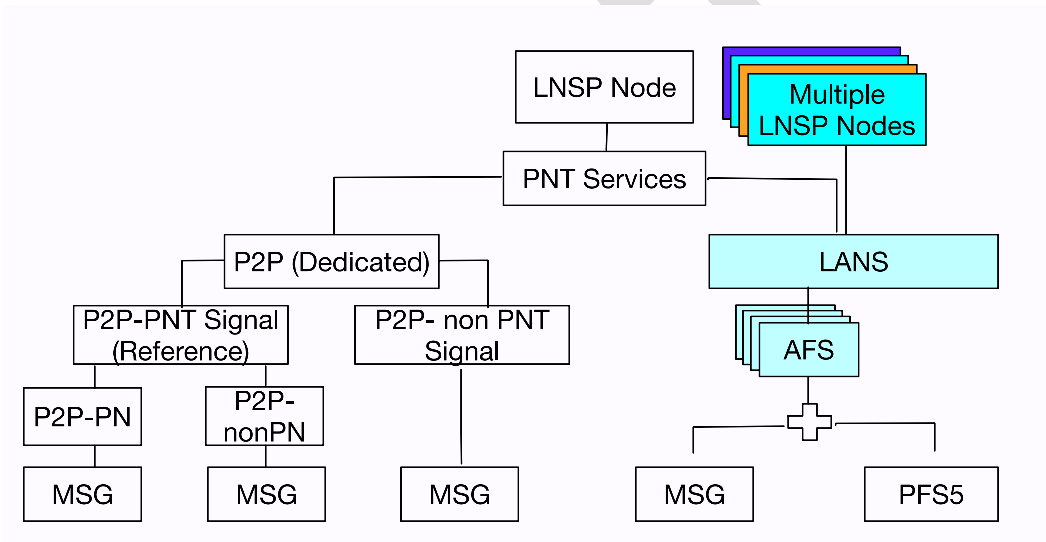

Figure 1 – PNT Services Provided by Multiple LNSP

This document is intended as a recommended standard, using a definition like Consultative Committee for Space Data Systems (CCSDS) standards. The adoption of the standard by a service provider is voluntary, however, as mentioned in LNIS, a service provider that claims to be LunaNet compliant (becoming an LNSP) must conform to this recommended standard in all of its parts.

LunaNet may encompass systems of different nature, including different orbits, different Earth segments, etc. Thus, some aspects of specific LunaNet services might be implemented differently by different LNSP, without impacting the service interoperability. Therefore, it is important to define specifications to the right level, leaving flexibility to each LNSP to implement their specific concepts, without impacting interoperability. For this reason, this document implements two categories of specifications, broadly defined as follows:

1) precise specifications are provided to avoid ambiguity, with no flexibility at the LNSP level.

2) general specifications are provided in order to guarantee interoperability and provide flexibility to the LNSP to define a specific implementation.

Per number 2 above, general specifications left for definition by the LNSP are referred to as *LNSP implementation flexibility*. Examples of LNSP implementation flexibility include but are not limited to the data content dissemination cadence, the update rate of the data, etc.

In order to achieve interoperability, the detailed definition covered by the LNSP implementation flexibility will need to be known to develop LunaNet compatible user terminals. Therefore, it is expected that an LNSP-specific signal in space interface control document (SISICD) will need to be generated and made available by the LNSP to a TBD distribution[1].

Future versions of this document will clarify the content associated with LNSP implementation flexibility.

In summary, each LNSP that intends to be interoperable as defined in LNIS shall:

1. comply with this document, and
2. define a SISICD[2] that provides definition to the items identified as having LNSP implementation flexibility in this document, and make it available to a TBD distribution, and
3. define user algorithms and models required to process the data specified in the provider specific SISICD and develop an example software implementation of the user processing, including test vectors, and make those available to the TBD distribution.

This document was written and reviewed by European Space Agency (ESA) and National Aeronautics and Space Administration (NASA).

1.1. SCOPE

This document defines, at the minimum, the specifications for interoperability among LNSP providing PNT services. It aims to maximize compatibility across multiple LNSP at the user level, while, at the same time, leaving sufficient flexibility to enable tailoring of the services and potential future evolutions.

1.2. ACRONYMS AND DEFINITIONS

1.2.1. ACRONYMS

Acronym	Definition
AD	Applicable Document
AFS	Augmented Forward Signal
BI	Block Interval
BPSK	Binary Phase Shift Key
CRC	Cyclic Redundancy Check
EIRP	Equivalent Isotropic Radiated Power
FID	Frame Identifier
GNSS	Global Navigation Satellite Systems

[1] The actual distribution list and/or the rules for the dissemination of the LNSP-specific SISICD will be clarified in the future.
[2] SISICD in this context means definition of signal characteristics and messages.

Acronym	Definition
ITOW	Interval Time of Week
LANS	Lunar Augmented Navigation Service
LNIS	LunaNet Interoperability Specification
LNSP	LunaNet Service Provider
LRT	LunaNet Reference Time
LSB	Least Significant Bit
MSB	Most Significant Bit
P2P	Peer-to-Peer
PNT	Position, Navigation, and Timing
RD	Reference Document
RHCP	Right-Hand Circularly Polarized
SB1	Subframe 1
SB2	Subframe 2
SB3	Subframe 3
SB4	Subframe 4
SECWEEK	Seconds in a week
SISE	Signal In Space Error
SISEvel	Signal In Space Error for velocity
SP	Synchronization Pattern
sps	Symbol per second
SV	Space Vehicle
WN	Week Number

1.2.2. DEFINITIONS

The following definitions are used throughout this document:

TBC: To Be Confirmed. It is used when a value is proposed, but it might change in future versions of this document.

TBD: To Be Determined. It is used when something is defined at a conceptual level, but no details are provided (e.g.: when a parameter is identified, but its numerical value is not yet defined).

TBW: To Be Written. It is used when a paragraph/section is planned to be written in future versions of this document.

The following conventions apply for the normative specifications in this Recommended Standard:

a. the words ‘shall’ and ‘must’ imply a binding and verifiable specification;
b. the word ‘should’ implies an optional, but desirable, specification;
c. the word ‘may’ implies an optional specification;
d. the words ‘is’, ‘are’, and ‘will’ imply statements of fact.

2. AUGMENTED FORWARD SIGNAL SPECIFICATIONS

2.1. INTERFACE DEFINITION

This section provides the specifications for the interfaces between the LNSP and the user of the AFS. The AFS is used within the LANS GNSS-like concept as detailed in LNIS. This section aims to provide enough information to ensure that the AFS broadcast by different LNSP can be used without major modifications by a receiver in cislunar space.

The interoperability among different LNSP is ensured by the compliance with the specifications in this document, compliance with the Signal in Space Error (SISE) requirements in LNIS, the Lunar Reference System and Lunar Time System Standard described in LNIS AD5, and, when relevant, compliance with LNIS AD3. The compliance to the SISE will ensure that the errors under control of the LNSP (e.g.: orbit prediction error, time synchronization error, satellite payload biases, etc.) are within a limit, guaranteeing the users that the errors remain within a predefined envelope.

The following approach is adopted for the messages:

- When a message is defined and/or specified in the same way (e.g.: at bit level) in multiple LunaNet PNT services (e.g. LANS and P2P), its definition is provided in LNIS AD3, so the related paragraph in section 2.4 includes the encapsulation of the message in AFS and refers to LNIS AD3 for the message detailed definition.
- When a message is implemented differently in AFS with respect to other LunaNet PNT services, its detailed specification and/or definition are provided in section 2.4.

2.1.1. AFS SIGNAL AND DATA STRUCTURE

The AFS signal defined in this document is a fixed frequency signal consisting of two main components: one denoted as AFS-I that is spread by a ranging code and modulated by a data message, and AFS-Q that is spread by a ranging code without any data message (pilot component).

AFS-I and AFS-Q use binary shift phase key (BSPK) modulation and are linearly multiplexed to generate the AFS signal as described in 2.2.2.

The AFS-I and AFS-Q components are transmitted using ranging codes defined in section 2.2.5.

The message structure and data encoding techniques for the data message on AFS-I are defined in section 2.3 and the content of the message transmitted by the AFS is provided in section 2.4.

2.2. AFS SIGNAL SPECIFICATIONS

2.2.1. COMPOSITE SIGNAL

2.2.1.1. FREQUENCY PLAN

LSIS-010: Frequency Band
The navigation signal shall be transmitted in S-band between 2483.5 MHz and 2500 MHz.
Note: This is in line with SFCG recommendation 32-2, that identifies the band between 2483.5 MHz and 2500 MHz for "In-situ Lunar based RNSS/RDSS to Lunar Orbit and Lunar Surface."

LSIS-020: Carrier Frequency
The navigation signal carrier frequency shall be 2492.028 MHz.

LSIS-030: Carrier Frequency maximum offset
The maximum deviation of the transmitted signal carrier frequency from the required signal carrier frequency shall be less than 10Hz TBC.
Note: The knowledge of the carrier frequency at the user level is bounded by the SISEvel requirement.

2.2.1.2. SIGNAL POLARIZATION

LSIS-040: Signal Polarization
The transmitted AFS signal shall be Right-Hand Circularly Polarized (RHCP).

LSIS-050: Signal Axial Ratio
The transmitted AFS shall preserve an RHCP signal axial ratio of less than 3 dB (TBC) over the antenna beamwidth that covers the service volume defined in LNIS.

2.2.1.3. CARRIER PHASE NOISE

LSIS-060: Navigation Signal Phase Noise
The phase noise spectral density of the un-modulated carrier shall allow a second-order phase locked loop with damping of 1 and with 10 Hz one-sided noise bandwidth to track the carrier to an accuracy of 0.02 (TBD) radians RMS.

2.2.1.4. SPURIOUS TRANSMISSIONS

LSIS-070: Maximum In-Band Spurious Transmissions
The aggregate EIRP of all unwanted emissions (including discrete emissions and parasitic emissions) integrated over the transmit bandwidth of each signal shall not exceed -35 dB (TBC) relative to the total power emitted in the bandwidth specified in 2.2.1.5.

LSIS-080: Maximum Out-Of-Band Emissions
TBW

2.2.1.5. CORRELATION LOSSES

Correlation loss is defined as the difference between the space vehicle (SV) power received per component in the bandwidth defined below and the signal power recovered in an ideal correlation receiver of the same bandwidth using an exact replica of the waveform within an ideal sharp-cutoff filter bandwidth centered at the carrier frequency specified in 2.2.1.1.

LSIS-090: Receiver reference bandwidth
The receiver reference bandwidth centered on the carrier frequency to be considered for the correlation losses shall be 15.944MHz (TBC).

LSIS-100: Correlation losses due to payload distortions
For each signal component, the correlation loss due to payload distortions shall be below 0.6 dB (TBC).

2.2.1.6. RECEIVED POWER LEVELS IN THE SERVICE VOLUME

LSIS-105: LNSP-Defined service volume
The LNSP shall identify in its SISICD any LNSP-specific service volume on or above the lunar geoid where its contribution to LANS is provided.

Note: The objective for LANS is to achieve full-service volume per LNIS. However, individual LNSP may focus on different volumes. LSIS-110 and LSIS-120 requirements apply to the LNSP-defined service volume.

LSIS-110: Minimum and maximum received power levels within LNSP-defined service volume
The minimum and maximum received power level at the lunar geoid (as defined in LNIS AD5) within the LNSP-defined service volume, with the following assumptions:

- an ideally matched 0dBi RHCP receiver antenna
- receiver antenna boresight direction pointing zenith (aligned to the vector starting at the center of the Moon towards the user receiver antenna)
- user antenna masking angle on the local horizon of 5 degrees

shall be according to Table 1.

Table 1: Received Minimum and Maximum Power

AFS Component	Received minimum power [dBW]	Received maximum power [dBW]
I	-166 (TBC)	-153 (TBC)
Q	-166 (TBC)	-153 (TBC)

Note: The power values in Table 1 are subject to revision and might change in future versions.

2.2.1.7. RECEIVED POWER LEVEL OUTSIDE THE LNSP-DEFINED SERVICE VOLUME

LSIS-120: Maximum received power levels outside the LNSP-defined service volume
The maximum received power level at the lunar geoid (as defined in LNIS AD5) outside the LNSP-defined service volume, with the following assumptions:

- an ideally matched 0dBi RHCP receiver antenna
- receiver antenna boresight direction pointing zenith (aligned to the vector starting at the center of the Moon towards the user receiver antenna)
- user antenna masking angle on the local horizon of 5 degrees

shall be according to Table 2.

Table 2: Received Maximum Power

AFS Component	Received maximum power [dBW]
I	-143 (TBC)
Q	-143 (TBC)

The signal may be transmitted outside the LNSP-defined service volume to enable opportunistic use. However, its power shall be within the maximum defined in Table 2 in order to minimize the noise on the user receiver.

Note: The power values in Table 2 are subject to revision and might change in future versions.

2.2.2. MODULATION

The navigation signal is composed of two components, one in-phase and one quadrature, called respectively data and pilot. Both components use Binary Phase Shift Keying (BPSK), with chip rate of n × 1.023 (Mchip/s); the data component consists of a BPSK (1) modulation, while the quadrature component is a BPSK (5). Figure 2 provides a generic view of the AFS generation.

LSIS-125: Signal multiplexing
The AFS components shall be linearly multiplexed according to Figure 2.

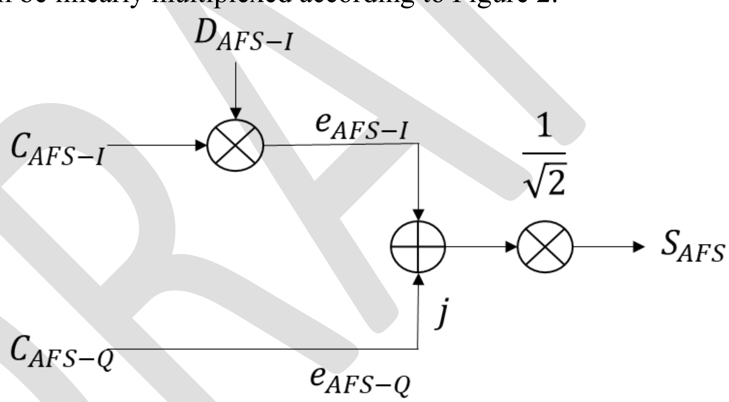

Figure 2: Modulation Scheme for AFS Signal

LSIS-130: Signal component generation
The AFS components shall be generated according to the following:

- e_{AFS-I} (data component) from the navigation data stream D_{AFS-I} modulated with the ranging code C_{AFS-I}
- e_{AFS-Q} (pilot component) from the ranging code C_{AFS-Q}

The mathematical description is:

$$s_{AFS}(t) = \frac{1}{\sqrt{2}}\left(e_{AFS-I}(t) + j e_{AFS-Q}(t)\right)$$

Where:

$$e_{AFS-I}(t) = \sum_{i=-\infty}^{+\infty}\left[c_{AFS-I,|i|_{L_{AFS-I}}} d_{AFS-I,|i|_{DC_{AFS-I}}} rect_{T_{c,AFS-I}}(t - iT_{c,AFS-I})\right]$$

$$e_{AFS-Q}(t) = \sum_{i=-\infty}^{+\infty} \left[c_{AFS-Q,|i|_{L_{AFS-Q}}} rect_{T_{c,AFS-Q}}(t - iT_{c,AFS-Q}) \right]$$

Table 3 provides the description of the parameters used in the equations.

Table 3: Signal Description Parameters

Parameter	Explanation	Unit
L_{AFS-I}, L_{AFS-Q}	Ranging code repetition period (data and pilot)	Chip
c_{AFS-I}, c_{AFS-Q}	Binary (NRZ modulated) ranging code (data and pilot)	N/A
d_{AFS-I}, k	k^{th}symbol of the navigation message	N/A
$T_{c,AFS-I}$, $T_{c,AFS-Q}$	Ranging code chip length (data and pilot)	s
DC_{AFS-I}	Number of chips per symbol	N/A
$\|i\|_{L_{AFS-I}}$, $\|i\|_{L_{AFS-Q}}$	i modulo L_{AFS-I} or L_{AFS-Q}	N/A
$rect_T\ (t)$	Function “rectangle” which is equal to 1 for $0 \leq t < T$ and equal to 0 elsewhere	N/A

LSIS-140: signal ranging code chip-rate and symbol-rate
The satellites shall transmit the AFS signal components with the ranging codes chip rates and symbol rates stated in Table 4.

Table 4: AFS Chip Rates and Symbol Rates

Component	Ranging code chip-rate [Mchip/s]	Symbol-rate [symbols/s]
I	1.023	500
Q	5.115	No data (pilot component)

2.2.3. LOGIC LEVELS

LSIS-150: Logic levels for the code bits
The correspondence between the logic level code bits used to modulate the signal and the signal level shall be according to the values stated in Table 6.

Table 5: Logical to Signal Level Assignment

Logic level	Signal level
1	-1.0
0	1.0

2.2.4. TRANSMITTED SIGNALS COHERENCY

LSIS-160: Primary code / data coherency
The code-data coherency between the primary code and data symbol shall be less than 0.5ns (TBC). Start of periodic spreading codes shall coincide with the start of a data symbol.
Note: The synchronization pattern is considered as data for the purpose of this requirement.

LSIS-170: Secondary Code / Primary Code Coherency
The code-code coherency between the primary and secondary codes shall be less than 0.5ns (TBC). The start of primary code shall coincide with the start of a secondary code chip.
Note: Secondary codes are defined in 2.2.5.2
Note: Code-Code Coherency is the time difference measured between code delays of any two signal components within the same signal.

LSIS-180: Code-Code (Data/Pilot) Coherency
The code-code coherency between the data and pilot component shall be less than 0.5ns (TBC). The edges of code chips shall be synchronous for the data and pilot components.
Note: Code-Code Coherency is the time difference measured between code delays of any two signal components within the same signal.

LSIS-190: Code/Carrier Phase Coherency
The maximum of the difference between code phase and carrier phase on any single signal component in any 8-hour period at the phase center of the satellite transmit antenna shall be less than 0.13 ns (1-sigma) (TBC).

2.2.5. SPREADING CODES CHARACTERISTICS

2.2.5.1. CODE LENGTHS

The ranging codes are built from so-called primary and secondary codes by using tiered codes construction described in paragraph 2.2.5.2.

LSIS-200: Codes Length and Duration
The code length to be used for each signal component shall be according to Table 6.

Table 6: Code Lengths

AFS Component	Primary code period [ms]	Secondary code period [ms]	Code length [chips]	
			Primary	Secondary
I	1 (TBC)	N/A	1023	N/A
Q	1 (TBC)	20 (TBC)	5115	20 (TBC)

LSIS-210: Code-Code (Data/Pilot) Synchronicity
The data and pilot primary and secondary code and the data symbols shall be transmitted according to Figure 3.

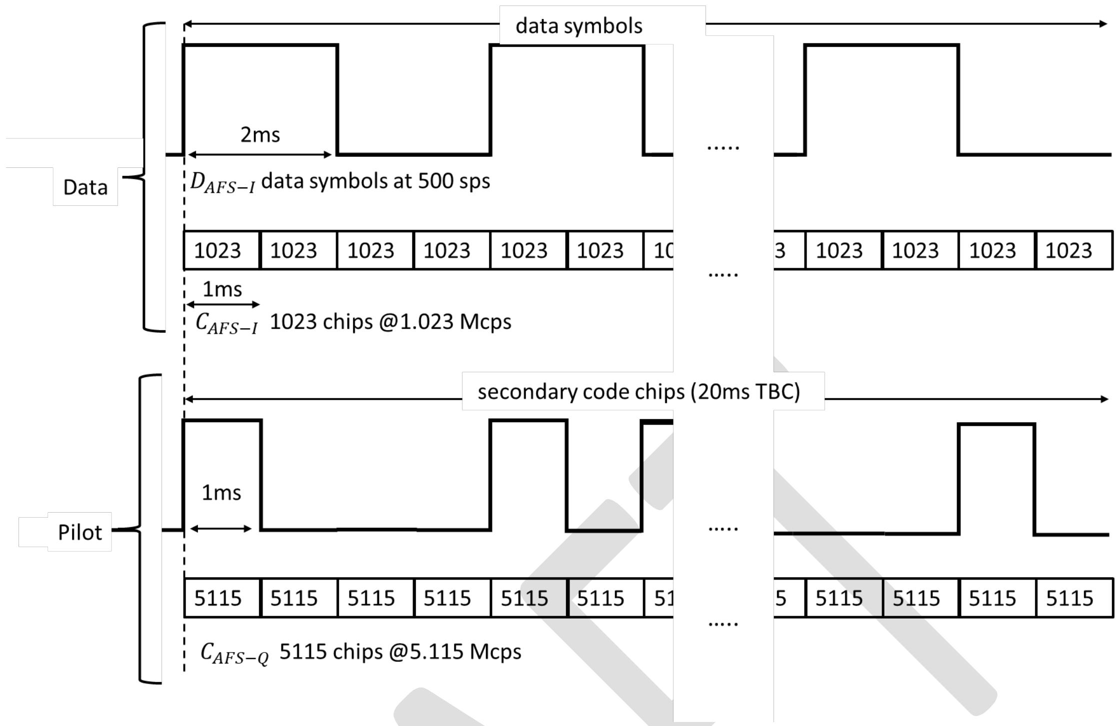

Figure3: Data and Pilot Channel Code and Data Synchronization

LSIS-220: Secondary Code Synchronization
The edge of the first chip of the secondary code shall be synchronized with the edge of the first chip of synchronization pattern (see 2.3.1.2).
Note: This requirement ensures that the secondary code is aligned with the synchronization pattern, and accordingly to the edge of the second as defined in 2.4.6

2.2.5.2. TIERED CODES GENERATION

Long spreading codes are generated by a tiered code construction, whereby a secondary code sequence is used to modify successive repetitions of a primary code, as shown in Figure 4 for a primary code of length N and chip rate f_c, and a secondary code of length N_S and chip rate f_{cs} (for actual values refer to paragraph 2.2.2 and 2.2.5.1). The duration of N chips is also called a primary code epoch in Figure 4. In logical representation, the secondary code chips are sequentially added (mod-2) with the primary code, always one chip of the secondary code per period of the primary code.

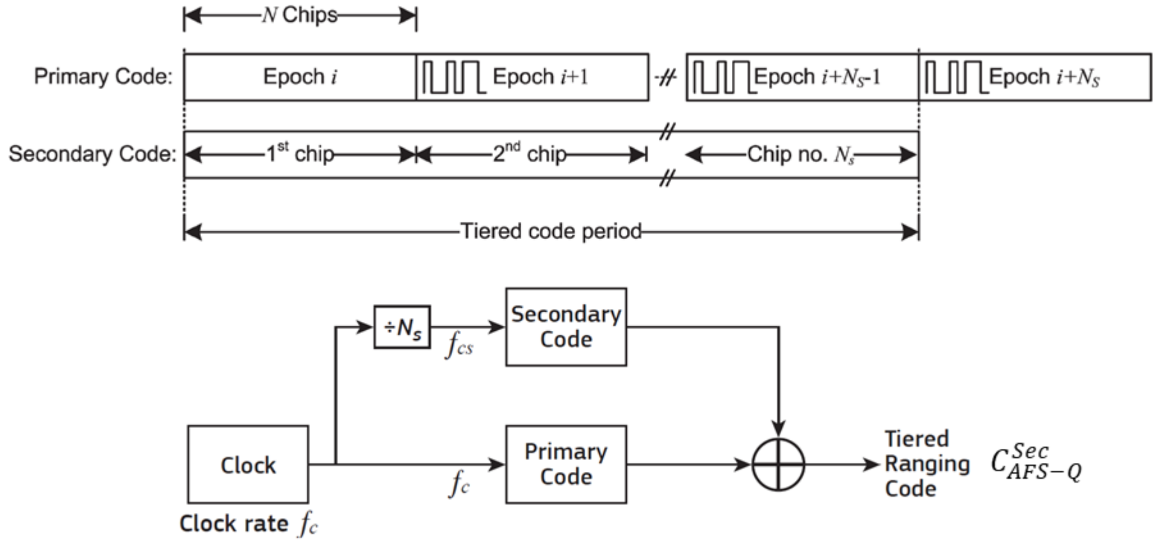

Figure4: Tiered Codes Generation with Secondary Code

The current structure of the pilot signal does not preclude the use of additional information provided in the pilot channel by means of overlay symbols on top of the pilot secondary code (e.g.: one symbol every one secondary code period), as shown in Figure 5. Examples of capabilities provided by the overlay codes are: faster synchronization with the 12 second data frame duration, faster provision of health status, faster time dissemination, etc.

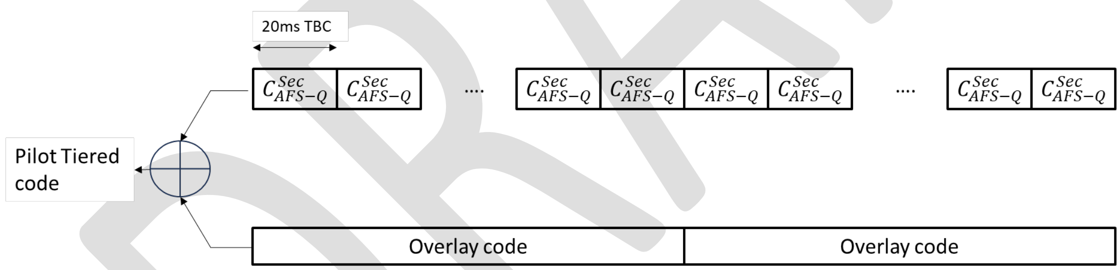

Figure5: Tiered Codes Generation with Overlay Code

2.2.5.3. PRIMARY CODES GENERATION AND DEFINITION

LSIS-230: Primary Code Assignment Per LNSP Satellite
Each LNSP satellite shall have unique data and pilot primary codes assigned.

TBW

2.2.5.4. SECONDARY CODE GENERATION AND DEFINITION

LSIS-240: Secondary Code Assignment Per LNSP Satellite
Each LNSP satellite shall have a unique secondary code assigned. (TBC)

TBW

2.2.5.5. CODE ASSIGNMENT TO SATELLITES/LNSP

TBW

2.3. AFS NAVIGATION MESSAGE FORMAT SPECIFICATION

2.3.1. GENERAL NAVIGATION MESSAGE STRUCTURE

LSIS-300: Spare Bits Definition
When not specified otherwise, the spare bits in the message structure shall be defined as a sequence of zeros and ones starting with zero on the MSB.

LSIS-310: Message Frame Structure
Each frame shall be composed of:

1) the uncoded synchronization pattern
2) one subframe (called SubFrame1, SB1) that contains at least the Time-Of-Interval (TOI) and the FrameID (FID)
3) and subsequent subframes that depend on the specific FID value.

See Figure 6.

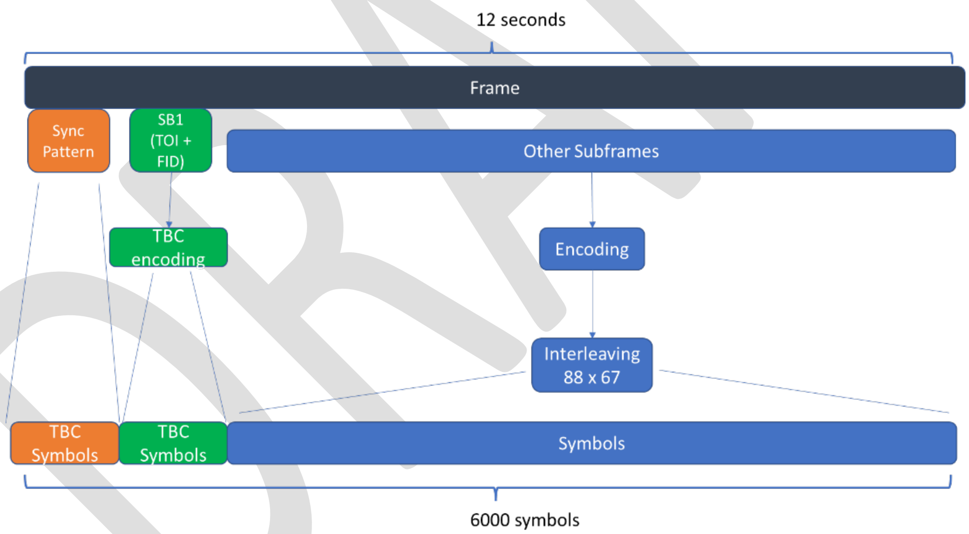

Figure 6: Navigation Message Generic Structure

2.3.1.1. BIT AND BYTE ORDERING CRITERIA

LSIS-320: Bit and Byte Ordering Criteria
All data values shall be encoded using the following bit and byte ordering criteria:

- For numbering, the most significant bit/byte is numbered as bit/byte 0
- For bit/byte ordering, the most significant bit/byte is transmitted first

2.3.1.2. SYNCHRONIZATION PATTERN

LSIS-330: Synchronization Pattern (SP)
The synchronization pattern (SP) shall be according to Table 7.
Note: The synchronization pattern allows the receiver to achieve synchronization to the frame boundary.

Table 7: Synchronization Pattern

Number of symbols	Binary pattern
TBD	TBD

LSIS-340: Uncoded Synchronization Pattern
The SP shall not be encoded.

2.3.1.3. INTERLEAVING

The 5896 (TBC) symbols representing the SB2, SB3, and SB4 are interleaved, after encoding, using a block interleaver. The block interleaver is conceptually described using a two-dimensional array of 67 (TBC) rows and 88 (TBC) columns. Symbols are written first (MSB first) into the interleaver from left to right starting at Row 1. After Row 1 is filled, Row 2 is filled from left to right and this process continues until the 5896th symbol (LSB of LDPC encoded symbol of the last subframe) is written into the rightmost cell of the last (67th) row. Once all 5896 symbols are written into the array, the symbols are sequentially read out of the array, for broadcast to user, from top to bottom starting at Column 1. After reading out the last symbol of the 67th row in Column 1, Column 2 symbols are read out from top to bottom and this process continues until the last symbol in the 67th row of the last column (88th) is read out.

LSIS-350: Symbol interleaving parameters
All the symbols of the frame, except for the SP and SB1 symbols, shall be interleaved according to the parameters in Table 8.

Table 8: Interleaving Parameters

Parameters	Values
Block interleaver size (symbols)	5896 (TBC)
Block interleaver dimensions (n columns x k rows)	88 x 67 (TBC)

2.3.2. SUBFRAME1 MESSAGE SPECIFICATION

2.3.2.1. SUBFRAME1 ENCODING

TBW

2.3.2.2. SUBFRAME1 (SB1) DATA SPECIFICATION

LSIS-400: Subframe 1 Data Bit Allocation
The TBC data bits of the SB1 shall be allocated in line with Table 9.

Table 9: Subframe1 Data Bits Allocation

SB1 data	
TOI	FID
9 (TBC)	TBD

LSIS-410: Subframe 1 Data Definition
The fields of the SB1 data shall follow the description in Table 10.

Table 10: SubFrame1 Fields Specification

Parameter	Definition	Bits	Scale factor	Unit	Values
TOI	Time of interval	9	N/A	dimensionless	0…399
FID	Frame ID	TBD	N/A	dimensionless	0…TBD

Note: The FID is used to identify the structure of the frame as described in 2.3.3. The TOI is used to reconstruct the time at the user level as described in 2.4.6.

2.3.3. FRAME STRUCTURE

The FrameID (FID) field is used to define different types of frames and allows for implementation of different schemes, including:

- different type of encoding of the "Other Subframes" other than SB1,
- different type and number of subframes.

LSIS-420: Frame Structure Identification
The frame structure shall be identified using the FrameID (FID) field in SB1 in line with the values in Table 11.

Table 11: Frame Structure Identification

FID	Definition	Reference
0	Frame structure including SB2, SB3 and SB4	Paragraph 2.3.3.1
1 to TBD	Reserved for future use	TBD

2.3.3.1. FRAMEID 0 MESSAGE STRUCTURE

In addition to the SP and SB1 that maintain the structure defined in 2.3.2, another 3 subframe types are specified within this frame type.

Subframe 2 (SB2) is always broadcast in every frame and its structure is not changing, as described in 2.3.3.1.4.

Subframe 3 (SB3) is a variable data frame that might contain different information. The specific information broadcasted is identified by the subframe identifier as described in 2.3.3.1.5.

Subframe 4 (SB4) is a variable frame that will contain variable data potentially supporting services other than the navigation service. Message specification is provided in 2.3.3.1.6.

Note for the current version of this document: The structure of the frame is meant to ensure dissemination of the mandatory and optional messages as defined in LNIS. At the same time, the proposed concept leaves flexibility to the LNSP to implement their specific concepts, so some aspects (e.g.: dissemination structure, dissemination frequency, etc.) are not specified in this version of the document. A clear example is the possibility to disseminate some messages in SB3 and/or SB4 and the possibility to use multiple frames to disseminate the complete message (e.g.: the almanac may be disseminated using multiple SB3 and/or SB4 over multiple frames). The next version of this document is expected to contain additional requirements to guide LNSP towards a common concept and ensure interoperability.

LSIS-430: FrameID 0 Structure Identification
The frame structure identified with FID equal to zero shall be in accordance with Figure 7.

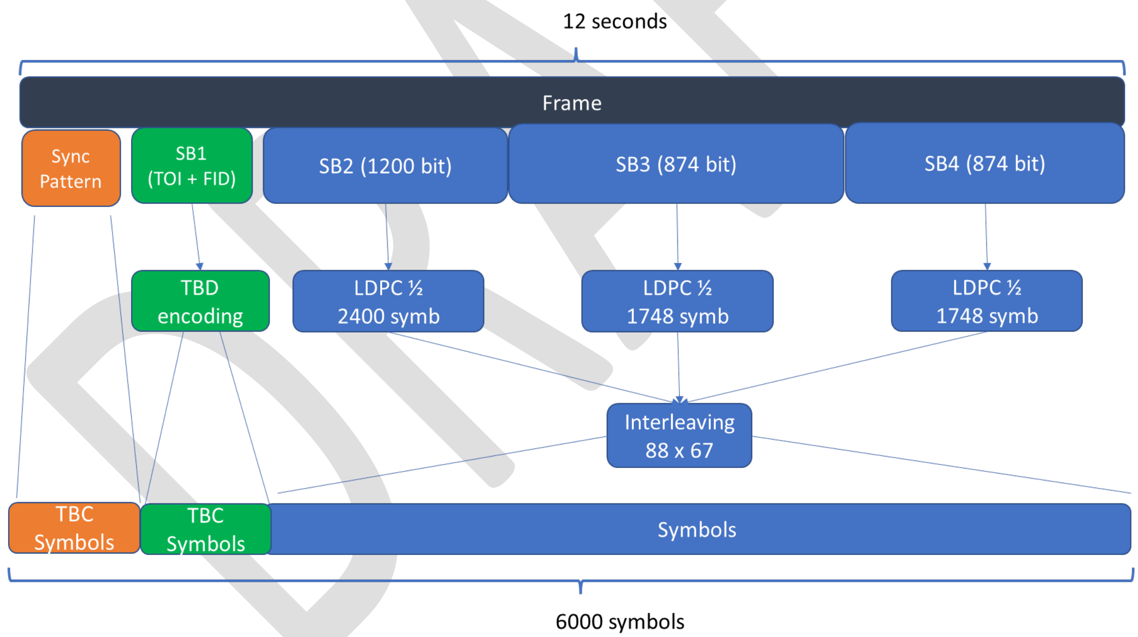

Figure7: Frame Structure of FrameID Equal to Zero (values are TBC)

2.3.3.1.1. SUBFRAME ENCODING (NON-SUBFRAME 1)

LSIS-440: Subframe 2 Encoding
The 1200 (TBC) bits of SB2 data shall be encoded using $^1/_2$ (TBC) LDPC codes.

LSIS-450: Subframe 3 Encoding
The 874 (TBC) bits of SB3 data shall be encoded using $^1/_2$ (TBC) LDPC codes.

LSIS-460: Subframe 4 Encoding
The 874 (TBC) bits of SB4 data shall be encoded using $^1/_2$ (TBC) LDPC codes.

2.3.3.1.2. LDPC ENCODING

TBW, details of the LDPC encoder structure will be provided in future versions of this document.

2.3.3.1.3. SUMMARY OF FRAMEID 0 ENCODING

This section provides a summary of the encoding parameters for the different subframes. The values in the table are TBC.

Table 12: FrameID=0 Bits and Symbols Allocation to Subframes

	bits	coding	coding rate	symbols
SubFrame2	1200	LDPC	1/2	2400
SubFrame3	874	LDPC	1/2	1748
SubFrame4	874	LDPC	1/2	1748

2.3.3.1.4. SUBFRAME 2 MESSAGE SPECIFICATIONS

LSIS-500: Subframe2 Dissemination
The SB2 shall be broadcast in every frame.

LSIS-510: Subframe2 Structure
The SB2 structure shall be identical in every frame.

LSIS-520: Subframe2 Dissemination
SB2 shall contain at least the following data:

- Clock and ephemeris data (CED) (MSG-G4, see also 2.4.4)
- Week Number (WN) (MSG-G8, precise definition provided in 2.4.2)
- Interval Time of Week (ITOW) (MSG-G8, precise definition provided in 2.4.2)
- Health status (MSG-G2, see also 2.4.3)
- Cyclic Redundancy Check (CRC) (see 2.4.1)

LSIS-530: Subframe2 Layout
The SB2 layout shall be according to Table 13.

Table 13: SubFrame2 Bits Allocation

Data	CRC
1176 (TBC)	24

LSIS-540: Subframe2 LNSP Specific Data
Additional data specified by the LNSP may be broadcasted in SB2 in addition to the mandatory data.

LSIS-550: Subframe2 Mandatory Spare Bits
TBC bits shall be kept as spare for future use.
Note: Spare bits shall be positioned before the CRC. Depending on the definition of the data field in SB2 the number of *spare bits might vary and potentially might be removed entirely.*

2.3.3.1.5. SUBFRAME 3 MESSAGE SPECIFICATIONS

The SB3 is a dynamic subframe that will have different structures depending on the SB3 type. This message may be used for multiple purposes, including specific custom messages from the LNSP that are not specified in this document (e.g.: proprietary messages).

LSIS-560: Subframe3 Layout
The SB3 layout shall be according to Table 14.

Table 14: SubFrame3 Bits Allocation

SB3 type	Data	CRC
4 or 6 (TBC)	844 or 846 (TBC)	24

LSIS-570: Subframe3 Dynamic Data Content
The SB3 data content shall be identified by the SB3 type field.

LSIS-580: Subframe3 Mandatory Type of Data Content
The following data shall be disseminated using SB3:

- Almanac data (note that the almanac data for the full constellation is expected to be disseminated using multiple SB3) (MSG-G5, see also 2.4.5).
- LunaSAR return link message (covering both MSG-S19 and MSG-S20, (precise definition provided in 2.4.8)
- Alerts messages (MSG-G24, precise definition in 2.4.15*)*.

Note: The data listed in this requirement does not need to be disseminated every frame, the frequency of the dissemination of the data *is not defined in this document. The data of a specific message might be disseminated over multiple frames.*

LSIS-590: Subframe3 Optional Type of Data Content
The following data should be disseminated using SB3:

- MAntennaProperties (MSG-G3)

- GNSS Augmentation (MSG-G23)
- Maneuver (MSG-G10)
- SAttitude State/ Ephemeris (MSG-G11)
- Conjunction (MSG-G14)
- Detection Alert (MSG-G24)
- Custom messages defined by the LNSP.

2.3.3.1.6. SUBFRAME 4 MESSAGE SPECIFICATIONS

The SB4 is a dynamic subframe that will have different structures depending on the SB4 type. This message may be used for multiple purposes, including specific custom messages from the LNSP that are not specified in this ICD (e.g.: proprietary messages).

LSIS-600: Subframe4 Layout
The SB4 layout shall be according to Table 15.

Table 15: SubFrame4 Bits Allocation

SB4 type	Data	CRC
4 or 6 (TBC)	844 or 846 (TBC)	24

LSIS-610: Subframe4 Dynamic Data Content
The SB4 data shall be identified by the SB4 type field.

LSIS-620: Subframe3 Mandatory Type of Data Content
The following data shall be disseminated using SB4:

- LunaNet Network Access Information (MSG-G1).

Note: The data listed in this requirement does not need to be disseminated in every frame, the frequency of the dissemination of the data is not defined in this document. The data of a specific message might be disseminated over multiple frames.

LSIS-630: Subframe4 Optional Type of Data Content
The following data should be disseminated using SB4:
- MAntennaProperties (MSG-G3)
- Almanac data (note that the almanac data for the full constellation is expected to be disseminated using multiple SB4) (MSG-G5, see also 2.4.5)
- Maneuver (MSG-G10)
- SAttitude State/ Ephemeris (MSG-G11)
- GNSS Augmentation (MSG-G23)
- Scheduling information for communication service (MSG-G27, MSG-G28)
- Updates of lunar maps or lunar DEM (MSG-G15)
- Ancillary info (MSG-G17)
- Conjunction (MSG-G14)
- Science data (MSG-G25)
- Acknowledge- of non-SAR MSG (MSG-G22)
- UIS Response (MSG-G27)
- FF Commands (MSG-G29)
- Custom messages defined by the LNSP.

Note: The data listed in this requirement does not need to be disseminated in every frame, the frequency of the dissemination of the data is not defined in this document. The data of a specific message might be disseminated over multiple frames.

2.3.3.1.7. ALLOCATION OF LUNANET MESSAGES TO SUBFRAMES

This section contains the mapping between LunaNet messages (see annex D of LNIS) with the subframes specified in this document. In line with LNIS, a label is used to identify which category applies to that message/service combination within the available AFS bandwidth: F = Fundamental, meaning it shall be broadcasted by the LNSP; O = Optional, meaning it might be broadcasted by the LNSP; and C = Comm, meaning it may be transmitted on AFS to facilitate LunaNet services.

Table 16: LNIS Message Allocation to Subframes

LunaNet Interoperability Specifications [AD.1]			**LSIS (this document)**	
MSG ID	**MSG Title**	**Category**	**SubFrame**	**Notes**
MSG-G1	LunaNet Network Access Information	F	SB4	periodic
MSG-G2	Health and Safety	F	SB2	periodic
MSG-G3	MAntennaProperties	O	SB3 and/or SB4	TBD
MSG-G4	Sorbit Ephemeris & clock correction	F	SB2	periodic
MSG-G5	MOrbit Almanac	F	SB3 and/or SB4	periodic
MSG-G8	Time of transmission	F	SB2 and SB3	periodic
MSG-G10	Maneuver	O	SB3 and/or SB4	Ad-hoc
MSG-G11	SAttitude State/ Ephemeris	O	SB3 and/or SB4	Ad-hoc
MSG-G14	Conjunction	O	SB3 and/or SB4	Ad-hoc
MSG-G15	Maplet	O	SB4	Ad-hoc
MSG-G17	Ancillary info	O	SB4	Ad-hoc
MSG-S19	Acknowledge- of SAR - LvL1	F	SB3	Ad-hoc
MSG-S20	Acknowledge- of SAR - LvL2	F	SB3	Ad-hoc
MSG-G22	Acknowledge- of non-SAR MSG	O	SB4	Ad-hoc
MSG-G23	GNSS Augmentation	O	SB3 and/or SB4	Ad-hoc
MSG-G24	Detection Alert	O	SB3	Ad-hoc
MSG-G25	Science	C	SB4	Ad-hoc
MSG-G27	UIS Response	C	SB4	Ad-hoc
MSG-G28	User Schedule Notice	C	SB4	Ad-hoc
MSG-G29	FF Commands	C	SB4	Ad-hoc

2.4. AFS MESSAGES AND DATA CONTENT

This chapter describes the messages and data content applicable to AFS. When a message is defined in the same way (e.g.: at bit level) in multiple LunaNet PNT services (e.g., LANS and P2P), the related paragraph includes the message encapsulation in AFS, while the message detailed definition is identified in LNIS AD3. Otherwise, each paragraph specifies the specific implementation applicable to AFS. In this case, the same type of message may be implemented differently in different LunaNet PNT services.

Note for the current version of this document: the content of many of the messages is currently undefined and it is expected to be specified in the next version of this document. It is important to note that different messages might follow different approaches. In general, we identify two ways to specify the content of a message:

1) *precise message specification is provided to avoid ambiguity, with no flexibility at the LNSP level (e.g.: CRC and MSG-G8)*
2) *General message specification is provided at higher level than the bit representation, the specification ensures that all the required information is defined, however the specific implementation is left free to the LNSP, and it is meant to be detailed in the LNSP-specific SISICD.*

This approach is currently under assessment and will be further detailed in the next version of this document, including which approach is planned to be adopted for each of the messages.

2.4.1. CHECKSUM

The checksum, which employs a CRC technique, is used to detect the reception of corrupted data.

LSIS-700: Checksum Field Generator Polynomial
For the SB2, SB3 and SB4 a CRC of 24 bits shall be generated from the following generator polynomial:

$$G(X) = (1 + X) * P(X)$$

where P(X) is the primitive and irreducible polynomial with the following definition:

$$P(X) = X^{23} + X^{17} + X^{13} + X^{12} + X^{11} + X^{9} + X^{8} + X^{7} + X^{5} + X^{3} + X^{1}$$

LSIS-710: Checksum Field Computation
The CRC shall be composed of a sequence of 24 parity bits p_i with the following values.
For any i from 1 to 24, p_i is the coefficient of X^{24-i} in $R(X)$,
Where:

- $R(X)$ is the remainder of the binary polynomial algebra division of the polynomial $m(X) \cdot X^{24}$ by $G(X)$

$m(X) = m_1 X^{k-1} + \cdots + m_{k-2} X^2 + m_{k-1} X + m_k$ with m_1, m_2, ... m_k the sequence of k-bits information to be protected by the CRC, and m_1 as the MSB.

2.4.2. LUNANET NETWORK ACCESS INFORMATION (MSG-G1)

TBW

2.4.3. HEALTH AND SAFETY (MSG-G2)

TBW

2.4.4. CLOCK AND EPHEMERIS DATA (CED, MSG-G4)

TBW, additional information will be provided in future versions of this document, but some preliminary information is provided to allow understanding of the type of information expected to be broadcast to the user. MSG-G4 is expected to contain or specify:

- *The data to allow a user to compute the position and velocity of the phase center of the navigation antenna of the LNSP satellite transmitting the AFS, in the reference frame defined in LNIS AD5*
- *the data to allow a user to correct any clock synchronization error impacting the AFS transmitted by LNSP satellite, in the time scale defined in LNIS AD5*
- *the validity period of the data contained in MSG-G4*
- *the reference epoch to which the data refers*
- *the expected quality estimated by the LNSP of the data contained in MSG-G4 (e.g.: similar to GPS URA or Galileo SISA)*

2.4.5. MORBIT ALMANAC (MSG-G5)

TBW

2.4.6. TIME OF TRANSMISSION (MSG-G8)

The time of transmission (ToT) may be retrieved by a receiver combining multiple fields provided in the navigation message and exploiting tracking of the spreading codes.

A user receiver may resolve the time (multiple of the frame duration) since the starting LunaNet Reference Time (LRT) epoch with the following formula:

$$T_F = WN * SECWEEK + ITOW * BI_d + TOI * F_d$$

Where

- T_F is the time in seconds since the starting LRT epoch, with increments that are a multiple of the duration of a frame.

The synchronization within the frame duration may be achieved counting the number of primary/secondary codes and the phase within the primary code since the leading edge of the first chip of the first code sequence of the frame (e.g.: the edge of the first chip of the synchronization pattern).

LSIS-720: ToT Fields Definition

The fields needed to retrieve time of transmission shall be in accordance with the following definitions (see Figure 8):

- <u>$SECWEEK$</u> is the number of seconds in a week (604800).
- <u>BI_d is the block interval duration</u> in seconds. This is computed multiplying the frame duration with the maximum TOI value (400) ($BI_d = 12 * 400\ (TBC)$ = 4800 (TBC) seconds = 1h20min).
- <u>F_d is the frame duration</u>, which length is 12 seconds.

- The Time of Interval (TOI) is represented with 9 (TBC) bits and represents the number of frames from the beginning of the block interval (BI). A BI lasts 4800 (TBC) seconds (1 hour and 20 minutes), a frame lasts for 12 seconds, so TOI needs to represent 400 (TBC) values. The TOI is referred to the leading edge of the first chip of the first code sequence of the frame (leading edge of the first chip of the SP).

$$TOI = floor\left[\frac{mod(t, BI_d)}{F_d}\right]$$

Where t is the time in seconds since the LRT start epoch.

- The Interval Time of week (ITOW) count is defined as being equal to the number of block intervals (BI) that have occurred since the transition from the previous week. The ITOW is represented with 7 (TBC) bits, covering the 126 (TBC) BI in a week.

$$ITOW = floor\left[\frac{mod(t, SECWEEK)}{BI_d}\right]$$

Where t is the time in seconds since the LRT start epoch.

- The Week Number (WN) is an integer counter that gives the sequential week number from the LRT start epoch. This parameter is represented with 13 (TBC) bits, which covers 8192 weeks (about 157 years). Then the counter is reset to zero to cover an additional period modulo 8192.

$$WN = floor\left[\frac{t}{SECWEEK}\right]$$

Where t is the time in seconds since the LRT start epoch.

- The LunaNet Reference Time (LRT) start epoch is TBD (LRT is defined in LNIS AD5).

Figure 8: Time of Transmission Concept

LSIS-730: ToT Fields Binary Representation
The fields required to retrieve ToT shall be according to Table 17.

Table 17: Time of Transmission Fields Binary Representation

Parameter	Definition	Bits	Scale factor	Unit	Values
TOI	Time of interval	9 (TBC)	N/A	dimensionless	0…399
ITOW	Interval time of week	7 (TBC)	N/A	dimensionless	0…125
WN	Week Number	13 (TBC)	1	week	0…8191

2.4.7. MANEUVER (MSG-G10)

TBW

2.4.8. SATTITUDE STATE/ EPHEMERIS (MSG-G11)

TBW

2.4.9. CONJUNCTION (MSG-G14)

TBW

2.4.10. MAPLET (MSG-G15)

TBW

2.4.11. ANCILLARY INFO (MSG-G17)

TBW

2.4.12. LUNASAR (MSG-S19 AND MSG-S20)

TBW

2.4.13. ACKNOWLEDGE OF NON-SAR MSG (MSG-G22)

TBW

2.4.14. GNSS AUGMENTATION (MSG-G23)

TBW

2.4.15. DETECTION ALERT (MSG-G24)

TBW

2.4.16. SCIENCE (MSG-G25)

TBW

2.4.17. UIS RESPONSE (MSG-G27)

TBW

2.4.18. USER SCHEDULE NOTICE (MSG-G28)

TBW

2.4.19. FF COMMANDS (MSG-G29)

TBW