The Consultative Committee for Space Data Systems

Draft Recommendation for Space Data System Standards

TM SYNCHRONIZATION AND CHANNEL CODING

PROPOSED DRAFT RECOMMENDED STANDARD

CCSDS 131.0-P-2.0

PROPOSED PINK SHEETS

May 2016

DOCUMENT CONTROL

Document	Title	Date	Status
CCSDS 131.0-B-1	TM Synchronization and Channel Coding, Issue 1	September 2003	Original issue
CCSDS 131.0-B-2	TM Synchronization and Channel Coding, Recommended Standard, Issue 2	August 2011	Current issue.
CCSDS 131.0-P-2.0	TM Synchronization and Channel Coding, Issue 2.0	May 2016	Current proposed draft update: – adds LCPC coding for a stream of Channel Access Data Units (CADUs); – deletes obsolete annex detailing changes from documents retired in 2005.

NOTE – Only pages containing substantive changes are included.

1.5 DOCUMENT STRUCTURE

This document is divided into eleven numbered sections and seven annexes:

a) section 0 presents the purpose, scope, applicability and rationale of this Recommended Standard and lists the conventions, definitions, and references used throughout the document;

b) section 2 provides an overview of synchronization and channel coding;

c) section 3 specifies convolutional coding;

d) section 4 specifies Reed-Solomon coding;

e) section 5 concatenated coding;

f) section 6 specifies Turbo coding;

g) section 7 specifies low-density parity-check coding of a Transfer Frame;

h) section 8 specifies low-density parity-check coding (of a stream of Channel Access Data Units);

i) section 9 specifies the frame synchronization scheme;

j) section 10 specifies the Pseudo-Randomizer;

k) section 11 specifies the allowed lengths of Transfer Frames;

l) section 12 lists the managed parameters associated with synchronization and channel coding;

m) annex A defines the service provided to the users;

n) annex B discusses security issues related to TM Channel Coding;

o) annex C provides the generator matrix circulant table applicable to rate-223/255 LDPC coding (7.3);

p) annex D lists acronyms and terms used within this document;

q) annex E provides a list of informative references;

r) annex F provides information on transformation between the Berlekamp (dual basis) and Conventional representations;

s) annex G provides information on Reed-Solomon coefficients;

~~t) annex H lists the changes from relevant previously published CCSDS Recommended Standards (references [E2] and [E3]).~~

1.7 PATENTED TECHNOLOGIES

The CCSDS draws attention to the fact that it is claimed that compliance with this document may involve the use of patents concerning Turbo Coding (section 6) and Low-Density Parity-Check Coding (section 7).

The CCSDS takes no position concerning the evidence, validity, and scope of these patent rights.

The holders of these patent rights have assured the CCSDS that they are willing to negotiate licenses under reasonable and non-discriminatory terms and conditions with applicants throughout the world. In this respect, the statements of the holders of these patent rights are registered with CCSDS. Information can be obtained from the CCSDS Secretariat at the address indicated on page i. Contact information for the holders of these patent rights is provided in annex B.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights other than those identified above. The CCSDS shall not be held responsible for identifying any or all such patent rights.

1.8 REFERENCES

The following documents contain provisions which, through reference in this text, constitute provisions of this Recommended Standard. At the time of publication, the editions indicated were valid. All documents are subject to revision, and users of this Recommended Standard are encouraged to investigate the possibility of applying the most recent editions of the documents indicated below. The CCSDS Secretariat maintains a register of currently valid CCSDS Recommended Standards.

[1] *TM Space Data Link Protocol*. Issue ~~1~~2. Recommendation for Space Data System Standards (Blue Book), CCSDS 132.0-B-~~1~~2. Washington, D.C.: CCSDS, September ~~2003~~2015.

[2] *AOS Space Data Link Protocol*. Issue ~~2~~3. Recommendation for Space Data System Standards (Blue Book), CCSDS 732.0-B-~~2~~3. Washington, D.C.: CCSDS, ~~July 2006~~September 2015.

[3] *Information Technology—Open Systems Interconnection—Basic Reference Model: The Basic Model*. 2nd ed. International Standard, ISO/IEC 7498-1:1994. Geneva: ISO, 1994.

[4] *Information Technology—Open Systems Interconnection—Basic Reference Model—Conventions for the Definition of OSI Services*. International Standard, ISO/IEC 10731:1994. Geneva: ISO, 1994.

[5] *Radio Frequency and Modulation Systems—Part 1: Earth Stations and Spacecraft*. Issue 25. Recommendation for Space Data System Standards (Blue Book), CCSDS 401.0-B-25. Washington, D.C.: CCSDS, ~~March 2003~~February 2015.

2.2.4 SYNCHRONIZATION

This Recommended Standard specifies a method for synchronizing Transfer Frames using an Attached Sync Marker (ASM) (see section 8).

The ASM may also be used for resolution of data ambiguity (sense of '1' and '0') if data ambiguity is not resolved by the modulation method used in the Physical Layer.

This Recommended Standard also defines a Code Sync Marker (CSM) (see section 8) that, when used, may also be used for resolution of data ambiguity. The CSM is not used for synchronizing Transfer Frames.

2.2.5 PSEUDO-RANDOMIZING

This Recommended Standard specifies a pseudo-randomizer to improve several aspects of the telemetry link that aid receiver acquisition, bit synchronization (see section 10), convolutional code synchronization, and proper Frame Validation (see 2.2.3).

2.3 INTERNAL ORGANIZATION OF SUBLAYER

2.3.1 SENDING END

Figure 2-2 shows the internal organization of the Synchronization and Channel Coding Sublayer of the sending end. This figure identifies functions performed by the sublayer[1] and shows logical relationships among these functions. The figure is not intended to imply any hardware or software configuration in a real system. Depending on the options actually used for a mission, not all of the functions may be present in the sublayer.

At the sending end, the Synchronization and Channel Coding Sublayer accepts Transfer Frames of fixed length from the Data Link Protocol Sublayer (see figure 2-1), performs functions selected for the mission, and delivers a continuous and contiguous stream of channel symbols to the Physical Layer. It should be noted that LDPC encoding of a stream of Channel Access Data Units (CADUs) includes codeword randomization and attachment of Code Sync Marker as detailed in section 8.

[1] Figures 2-2 and 2-3 are limited to the contents of this recommended standard and does not cover, e.g., SCCC (reference [E6]) and DVB-S2 (reference [E7]).

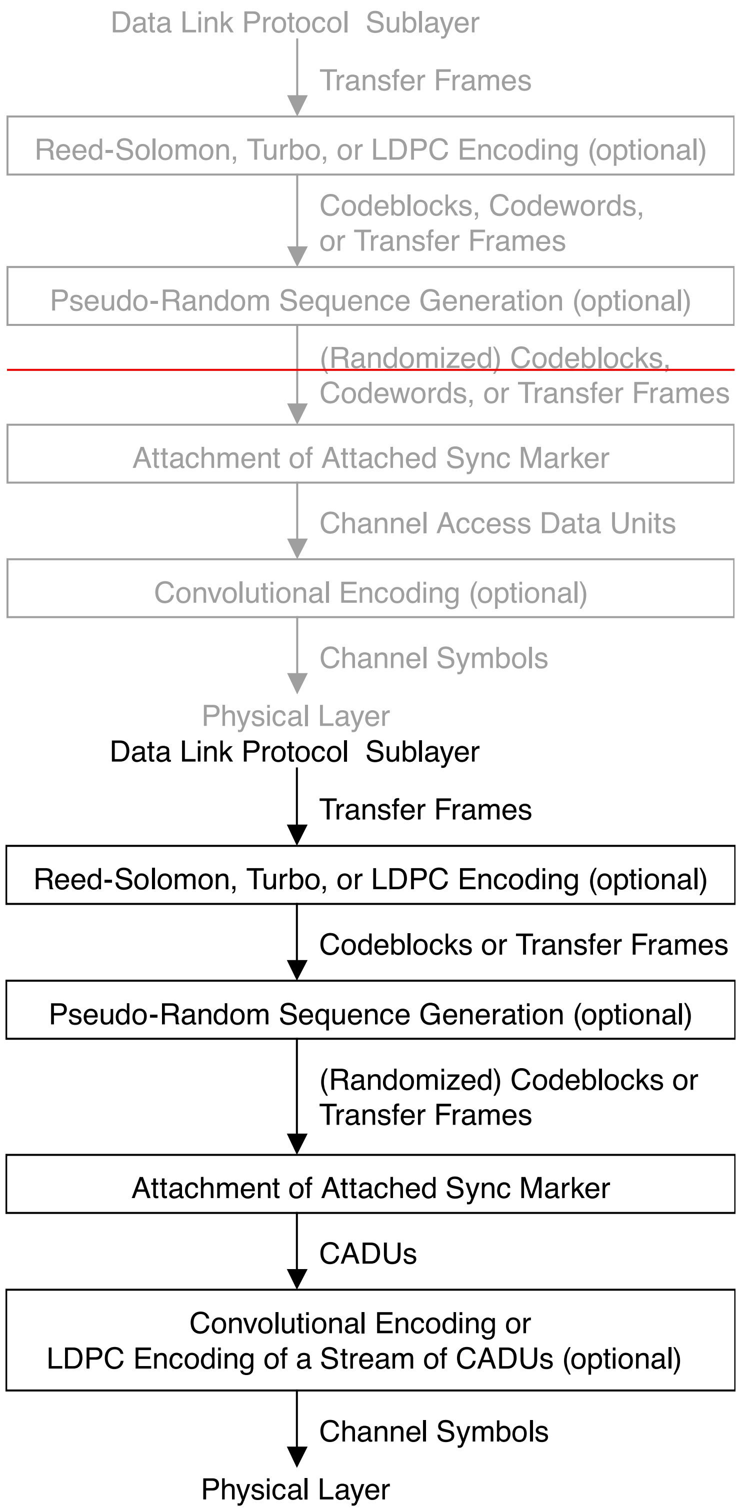

Figure 2-2: Internal Organization of the Sublayer at the Sending End

2.3.2 RECEIVING END

Figure 2-3 shows the internal organization of the Synchronization and Channel Coding Sublayer of the receiving end. This figure identifies functions performed by the sublayer and shows logical relationships among these functions. The figure is not intended to imply any hardware or software configuration in a real system (e.g., some implementations perform frame synchronization before convolutional decoding when convolutional code rate 1/2 is used) . Depending on the options actually used for a mission, not all of the functions may be present in the sublayer.

At the receiving end, the Synchronization and Channel Coding Sublayer accepts a continuous and contiguous stream of channel symbols from the Physical Layer, performs functions selected for the mission, and delivers Transfer Frames to the Data Link Protocol Sublayer. It should be noted that LDPC decoding of a stream of CADUs includes Code Sync Marker detection and codeword derandomization as detailed in section 8.

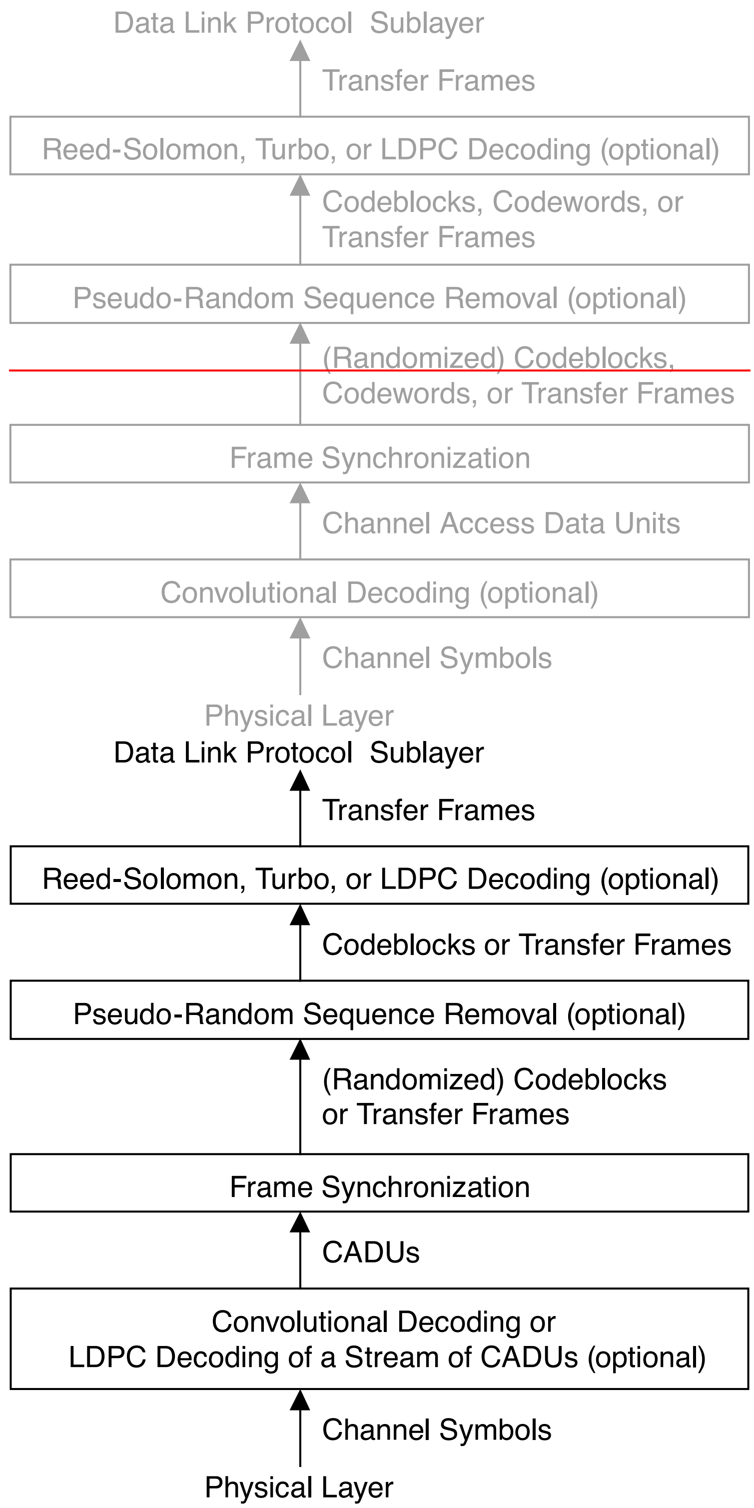

Figure 2-3: Internal Organization of the Sublayer at the Receiving End

7 LOW-DENSITY PARITY-CHECK CODING OF A TRANSFER FRAME

7.1 OVERVIEW

Low-Density Parity-Check (LDPC) codes are binary block codes with large codewords (hundreds or thousands of bits). They may be used to obtain greater coding gains than those provided by concatenated coding systems.

An LDPC code is specified indirectly by a v-by-w parity check matrix H consisting of v linearly independent rows. Parity check matrices may include additional linearly dependent rows without changing the code. A coded sequence of w bits must lie in the $w–v$ dimensional dual space of H; that is, it must satisfy all v parity check equations corresponding to the v rows of H. Alternatively, the code can be described through a (w–v)-by-w generator matrix G; such that a coded sequence lies in the w–v dimensional space of G. An encoder maps an input frame of k information bits uniquely into a codeword of n bits. LDPC codes may be shortened or expurgated so that $k<w–v$, and the remaining dimensions of the code remain unused. LDPC codes may also be extended or punctured to make n greater or less than w.

The distinguishing feature of LDPC codes is to have a low density of ones in the matrix H. Conversely, the generator matrix G is usually dense; that is, its density of ones is in the same order of that of zeros, at least for the non-systematic part of G.

Subsection 7.3 describes a code with a rate of 223/255 (approximately 7/8), and 7.4 describes a set of nine codes with rates 1/2, 2/3, and 4/5. These codes are systematic and non-transparent.

7.2 GENERAL

7.2.1 SYNCHRONIZATION

7.2.1.1 The (8160,7136) code defined in 7.3 shall be used with the 32-bit ASM shown in figure 9-1.

7.2.1.2 All of the nine codes with rates 1/2, 2/3, and 4/5, defined in 7.4, shall be used with the 64-bit ASM shown in figure 9-2.

NOTE – Differential encoding does not provide benefits with LDPC codes, and the ASM can also be used to resolve phase ambiguities. In fact, differential encoding before the LDPC encoder cannot be used because the LDPC codes recommended in this document are non-transparent, and differential encoding after the LDPC encoder is not advised because it introduces considerable loss of performance. It also would require differential detection, which is more complex with soft symbols. This implies that phase ambiguities have to be detected and resolved before decoding.

8 LOW-DENSITY PARITY-CHECK CODING OF A STREAM OF CHANNEL ACCESS DATA UNITS

8.1 OVERVIEW

The codes covered in this section are the same codes as the LDPC codes in section 7. In that section, a complete transfer frame is encoded within a single LDPC codeword. In this section transfer frames, each with a preceding Attached Synchronizer Marker (ASM) are organized into an octet stream of CADUs to be LDPC encoded such that a LDPC codeword(s) contains a (encoded) part of that octet stream.

The transfer frame plus preceding ASM is referred to as a Channel Access Data Unit (CADU) as per 9.1.2. The octet stream of CADUs is sliced into blocks that are the length of the message size of the chosen LDPC code. The size, *k*, depends on the selected LDPC code (see section 7). Since the CADU and the blocks are not aligned, an additional marker is required at the receive side of the link to synchronize the decoding. This marker is referred to as a Code Synchronization Marker (CSM). Each block is encoded to a LDPC codeword and one or more codewords may be combined into a LDPC codeblock. The codeblock length is managed and fixed for a given mission phase. A CSM is attached (i.e. immediately precedes) an LDPC codeblock.

With this coding option, the transfer frame length is irrelevant to the slicing and coding process, as shown in figure 8-1. A transfer frame may spill over from one codeword to the next one or be shorter than the codeword message size and be fully contained in a single codeword. Upon reaching the end of the data area of the codeword, the following octet in the octet stream is placed in the first position of the following codeword.

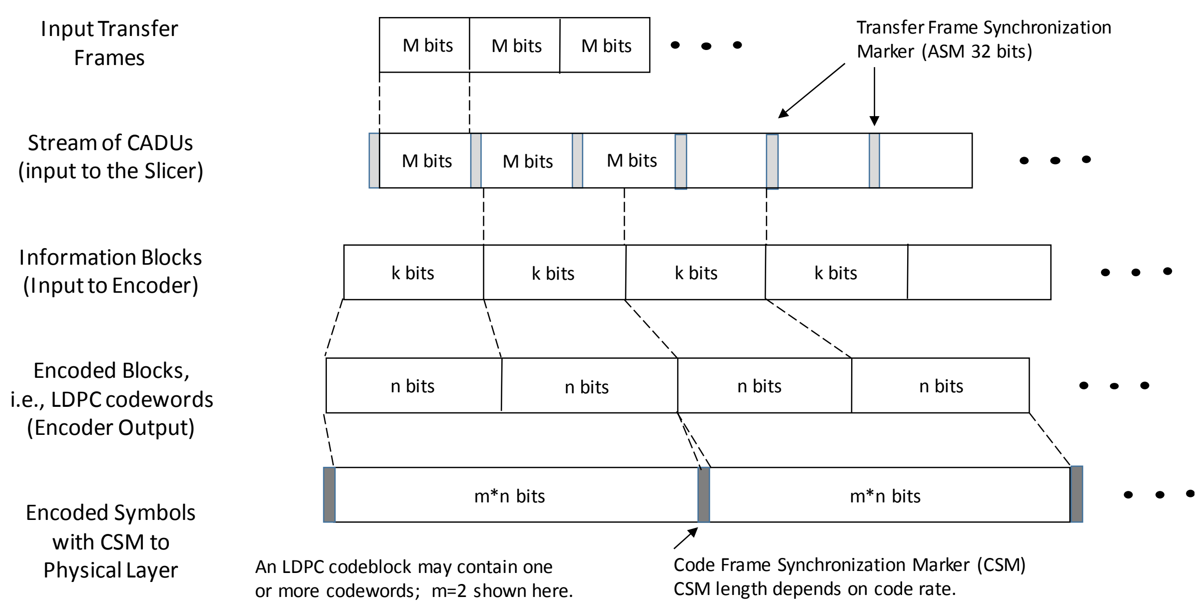

Figure 8-1: Transfer Frames Sliced to Form LDPC Codeblocks

8.2 GENERAL

8.2.1 SYNCHRONIZATION

At the receiver, two levels of synchronization are required: codeblock synchronization (identified by the CSM) and transfer frame synchronization (identified by the ASM). The ASM insertion is defined in section 9 and the data unit that consists of the ASM and the Transfer Frame is called the Channel Access Data Unit (CADU) as per 9.1.2.

8.2.2 THE ATTACHED SYNCHRONIZATION MARKER

Transfer Frames shall be identified by detecting the Attached Sync Marker (ASM) between them.

NOTES

1 The applicable ASM bit pattern is defined in 9.3.5.

2 The ASM will be LDPC encoded.

8.2.3 THE CODE SYNCHRONIZATION MARKER (CSM)

LDPC Codeblocks shall be synchronized by inserting a Code Sync Marker (CSM) between them.

NOTE – Synchronization is acquired on the receiving end by recognizing the specific bit pattern of the CSM in the symbol stream; synchronization is then verified by making further checks. The codeword and codeblock lengths are fixed and managed for a given phase of a mission.

8.2.4 CSM BIT PATTERNS

8.2.4.1 The CSM shall consist of a marker with a pattern as shown in table 8-1.

Table 8-1: CSM Bit Patterns

Code Rate	CSM Length	CSM Sequence (hex)
7136/8160 (~ 7/8)	32	1ACFFC1D
1/2, 2/3, 4/5	64	034776C7272895B0

8.2.4.2 The code with rate 7/8 shall use the 32 bit CSM defined in table 8-1.

NOTE – The 32-bit CSM pattern is the same as shown in table 8-1 as the ASM pattern. There is no conflict with the ASM since the ASM is randomized and will not appear at the decoding level.

8.2.4.3 All of the nine codes with rate 1/2, 2/3, 4/5 shall use the 64 bit CSM defined in table 8-1.

NOTE – It is advised not to use differential encoding with LDPC encoding. Differential encoding does not provide benefits with LDPC codes, and the CSM can be used to resolve phase ambiguities. In fact, differential encoding before the LDPC encoder cannot be used because these LDPC codes are non-transparent, and differential encoding after the LDPC encoder is not advised because it introduces considerable loss of performance. It also would require differential detection, which is more complex with soft symbols. This implies that receiver phase ambiguities have to be detected and resolved before decoding.

8.2.5 FRAME VALIDATION

The LDPC decoder may be used alone to validate the codeword, and consequently the contained TM Transfer Frame(s) (reference [1]) or AOS Transfer Frame (reference [2]). Whenever a LDPC codeword fails decoding, the Quality Indicator (see annex A) of all the Transfer Frames affected by that decoding shall be set to show that there is an uncorrectable error in received Transfer Frame(s).

NOTE – The Frame Error Control Field (FECF) specified in references [1] and [2] is optional, and the system designer may choose to use it for additional checks.

8.2.6 ENCODING PROCESS AT SENDING END

8.2.6.1 The encoding process at the sending end shall perform the functions described here and shown in figure 8-2 a).

8.2.6.2 The Encoding Process at the sending end shall add an ASM to each of the transfer frames creating a stream of CADUs.

8.2.6.3 The Encoding Process at the sending end shall extract an Information Block size portion (slice) of k bits from the stream.

8.2.6.4 The Encoding Process at the sending end shall encode each slice forming a LDPC codeword of n bits.

8.2.6.5 A LDPC codeblock shall be formed by aggregating “m” LDPC codewords (per managed parameters).

8.2.6.6 Each codeblock shall be randomized using the process articulated in section 10 and elaborated in 8.4 below.

8.2.6.7 A Code Synchronization Marker (CSM) shall be prepended to the codeblock.

8.2.7 DECODING PROCESS AT THE RECEIVING END

On the receive side, the reverse process is followed as shown in figure 8-2 b).

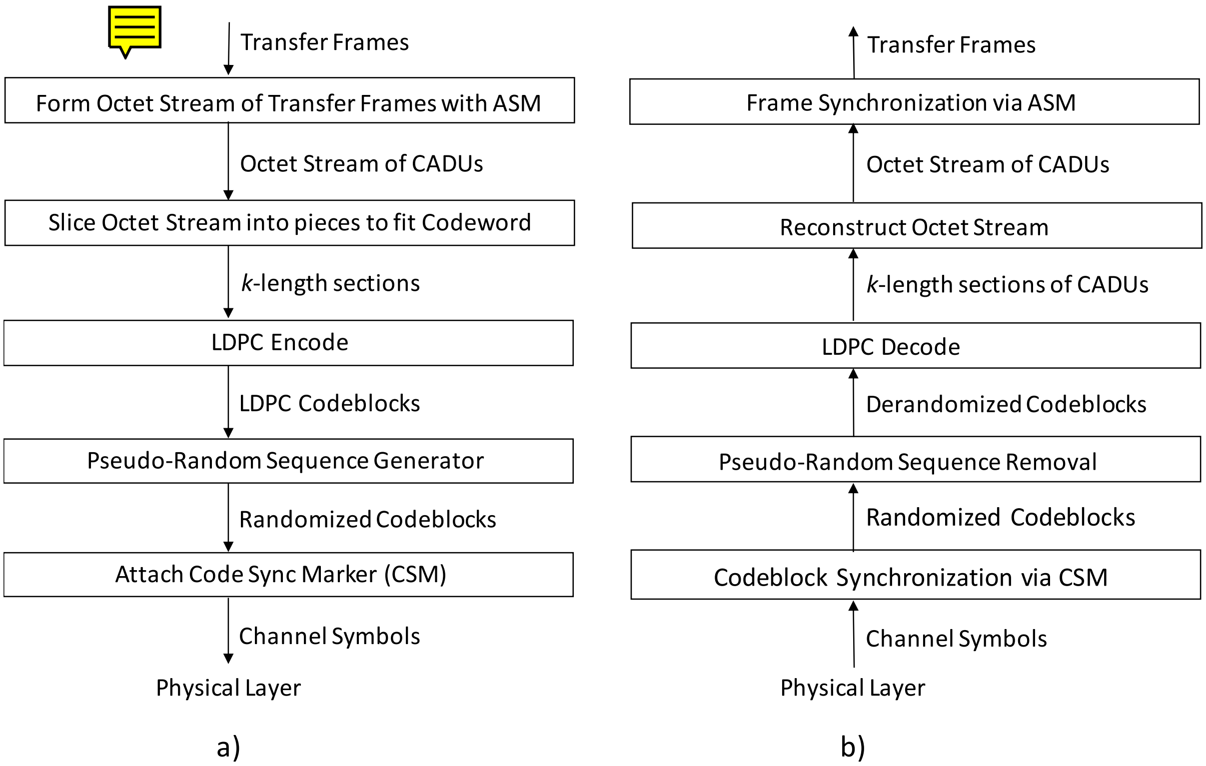

Figure 8-2: Sending and Receiving Side Processes

8.3 LOCATION OF CSM

8.3.1 The CSM shall immediately precede the LDPC codeblock.

8.3.2 The CSM shall immediately follow the end of the preceding codeblock; i.e., there shall be no intervening bits (data, code, or fill) preceding the CSM.

8.3.3 The CSM shall not be presented to the input of the LDPC encoder (or decoder).

8.4 RANDOMIZATION

8.4.1 Each LDPC codeblock shall be randomized using the pseudo-randomizer defined in 10.4 and 10.5.

NOTES

1 Prior to being encoded, the Transfer Frame in the CADU is not randomized.

2 The pseudo-randomizer is useful in avoiding several potential problems.

a) LDPC codes cannot guarantee sufficient bit transitions to keep receiver symbol synchronizers in lock.

b) Because of the quasi-cyclic nature of these codes, undetected decoding errors may result from incorrect codeblock synchronization.

c) LDPC codes cannot guarantee signal acquisition and mitigate spectral lines in the transmitted signal.

8.4.2 The pseudo-random sequence shall be applied starting with the first bit of the LDPC codeblock. On the sending end, the codeblock shall be randomized by exclusive-ORing the first bit of the codeblock with the first bit of the pseudo-random sequence, followed by the second bit of the codeblock with the second bit of the pseudo-random sequence, and so on, repeating the randomizer pattern as necessary.

NOTE – The configuration at the sending end is shown in figure 8-3.

8.4.3 On the receiving end, the original codeblock can be reconstructed (i.e., de-randomized) using the same pseudo-random sequence.

8.4.4 After locating the CSM in the received data stream, the data immediately following the CSM shall be de-randomized.

NOTES

1 The CSM is not randomized and is not de-randomized.

2 Since the slice is randomized after being encoded, any ASM present in a slice gets randomized.

3 De-randomization can be accomplished by performing exclusive-OR with hard bits or inversion with soft bits.

4 There is no reset of the randomizer at codeword boundaries within the codeblock.

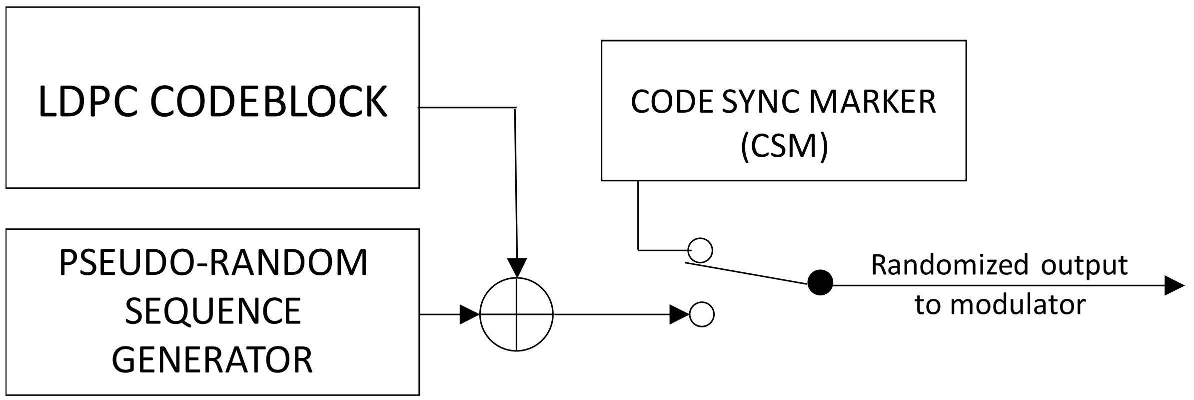

Figure 8-3: Pseudo-Randomizer Configuration

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9 FRAME SYNCHRONIZATION

9.1 OVERVIEW

9.1.1 SYNCHRONIZATION

Frame or Codeblock synchronization is necessary for proper decoding of Reed-Solomon, Turbo, and LDPC Codewords, and subsequent processing of the Transfer Frames. Furthermore, it is necessary for synchronization of the pseudo-random generator, if used (see section 10). It is also useful in assisting the node synchronization process of the decoder for the convolutional code.

For a coding system using the basic convolutional code specified in 3.3, the ASM can be acquired either in the channel symbol domain (i.e., before any decoding) or in the domain of bits decoded by the convolutional decoder.

For a concatenated Reed-Solomon and convolutional coding system using the basic convolutional code specified in 3.3, the ASM can be acquired either in the channel symbol domain (i.e., before any decoding) or in the domain of bits decoded by the inner code (i.e., the code symbol domain of the Reed-Solomon code).

For a coding system using the punctured convolutional codes specified in 3.4, the ASM can only be acquired in the domain of bits decoded by the convolutional decoder. It cannot be acquired in the channel symbol domain (i.e., before any decoding).

For a concatenated Reed-Solomon and convolutional coding system using the punctured convolutional codes specified in 3.4, the ASM can only be acquired in the domain of bits decoded by the inner code (i.e., the code symbol domain of the Reed-Solomon code); i.e.; it cannot be acquired in the channel symbol domain (i.e., before any decoding).

For a Turbo or LDPC coding system, the ASM can only be acquired in the channel symbol domain (i.e., before any decoding in the code symbol domain of the Turbo or LDPC code).

9.1.2 CHANNEL ACCESS DATA UNIT

~~The data unit that consists of the ASM and the Transfer Frame (if the Physical Channel is not Reed-Solomon, Turbo, or LDPC coded) or the Reed-Solomon Codeblock or Turbo or LDPC Codeword (if the Physical Channel is Reed-Solomon, Turbo, or LDPC coded) is called the Channel Access Data Unit (CADU). The Transfer Frame, Codeword, or Codeblock in the CADU may or may not randomized.~~

This Recommended Standards defines data unit called the Channel Access Data Unit (CADU) whose contents are as per attached table 9-1. The Transfer Frame, codeword, or codeblock in the CADU may or may not be randomized.

NOTE – The term ‘CADU’ originated in reference [E3] and is now in established use, even though it may not be applicable to a channel.

Table 9-1: Channel Access Data Unit Content with Different Coding Schemes

Applied Coding Scheme	CADU
Convolutional Coding	ASM and the Transfer Frame
Reed-Solomon Coding	ASM and Reed-Solomon Codeblock
Concatenated Coding	ASM and Reed-Solomon Codeblock
Turbo Coding	ASM and Turbo Codeword
Low-Density Parity-Check Coding (of a Transfer Frame)	ASM and LDPC Codeword
Low-Density Parity-Check Coding (of a stream of CADUs)	ASM and the Transfer Frame

9.2 THE ATTACHED SYNC MARKER (ASM)

9.2.1.1 Reed-Solomon Codeblocks or Turbo or LDPC Codewords (or Transfer Frames, if the Physical Channel is not Reed-Solomon, Turbo, or LDPC coded) shall be synchronized by using a stream of fixed-length Codeblocks or Codewords (or Transfer Frames) with an Attached Sync Marker (ASM) between them.

NOTE – Synchronization is acquired on the receiving end by recognizing the specific bit pattern of the ASM in the Physical Channel data stream; synchronization is then verified by making further checks.

9.2.1.2 If convolutional code is used, the ASM shall be convolutionally encoded.

9.2.1.3 If an inner convolutional code is used in conjunction with an outer Reed-Solomon code, the ASM shall be encoded by the inner code but not by the outer code. (See section 3.)

9.3 ASM BIT PATTERNS

9.3.1 The ASM for data that is not Turbo or LDPC coded shall consist of a 32-bit (4-octet) marker with a pattern shown in figure 9-1.

9.3.2 The ASM for data that is Turbo coded with nominal code rate r = 1/2, 1/3, 1/4, or 1/6 shall consist of a 32/r-bit (4/r-octet) marker with bit patterns shown in figures 9-2 through 9-5.

9.3.3 The ASM for data that ~~is~~applies LDPC ~~coded~~coding of a transfer frame (section 7) with nominal code rate r = 7/8 shall consist of a 32-bit marker with bit pattern shown in figure 9-1.

9.3.4 The ASM for data that ~~is~~applies LDPC ~~coded~~coding of a transfer frame (section 7) with code rate *r* = 1/2, 2/3, or 4/5 shall consist of a 64-bit marker with bit pattern shown in figure 9-2.

9.3.5 The ASM for data that applies LDPC coding of a stream of CADUs (section 8) shall consist of a 32-bit marker with bit pattern shown in figure 9-1.

NOTE – The ASM bit patterns are represented in hexadecimal notation as:

ASM for uncoded data, convolutional, Reed-Solomon, concatenated, ~~and~~ rate-7/8 LDPC for Transfer Frame, and all LDPC with CADU stream coded data:	1ACFFC1D
ASM for rate-1/2 Turbo and rates 1/2, 2/3, and 4/5 Transfer Frame LDPC coded data:	034776C7272895B0
ASM for rate-1/3 Turbo coded data:	25D5C0CE8990F6C9461BF79C
ASM for rate-1/4 Turbo coded data:	034776C7272895B0 FCB88938D8D76A4F
ASM for rate-1/6 Turbo coded data:	25D5C0CE8990F6C9461BF79C DA2A3F31766F0936B9E40863

FIRST TRANSMITTED BIT
(Bit 0)
↓
0001 1010 1100 1111 1111 1100 0001 1101
↑
LAST TRANSMITTED BIT
(Bit 31)

Figure 9-1: ASM Bit Pattern for Uncoded, Convolutional, Reed-Solomon, Concatenated, ~~and~~ Rate 7/8 LDPC ~~Coded Data~~ (Applied to a Transfer Frame), and LDPC (Applied to a Stream of CADUs) Coded Data

FIRST TRANSMITTED BIT
(Bit 0)
↓
0000001101000111011101101100011100100111001010001001010110110000
↑
LAST TRANSMITTED BIT
(Bit 63)

Figure 9-2: ASM Bit Pattern for Rate 1/2 Turbo and Rates 1/2, 2/3, and 4/5 LDPC (Applied to a Transfer Frame) Coded Data

10 PSEUDO-RANDOMIZER

10.1 OVERVIEW

In order for the receiver system to work properly, every data capture system at the receiving end requires that the incoming signal have sufficient bit transition density (see recommendation 2.4.9 in reference [5]), and allow proper synchronization of the decoder. The incoming signal must also be free of significant spectral lines, and be free of patterns that interfere with codeword synchronization and validation (see 2.2.2).

NOTE – Designers should note that the length-255 pseudo-randomizer may introduce spectral lines at 1/255 of the symbol rate, and these may be significant in some systems.

In order to ensure proper receiver operation, the data stream must be sufficiently random. The Pseudo-Randomizer defined in this section is the preferred method to ensure sufficient randomness for all combinations of CCSDS-recommended modulation and coding schemes. The Pseudo-Randomizer defined in this section is required unless the system designer verifies proper operation of the system if this Randomizer is not used.

NOTE – Problems with telemetry links have been encountered because this Pseudo-Randomizer was not used, and sufficient randomness was not ensured by other means and properly verified.

The presence or absence of pseudo-randomization is fixed for a Physical Channel and is *managed* (i.e., its presence or absence is not signaled in the transmitted data stream but must be known a priori) by the receiver.

10.2 PSEUDO-RANDOMIZER DESCRIPTION

NOTE – This subsection (including figure 10-1) does not apply to the case of LDPC encoding of a stream of CADUs, where a CSM (and not an ASM) is added (see 8.4 and figure 8-3).

10.2.1 The method for ensuring sufficient transitions is to exclusive-OR each bit of the Codeblock, Codeword, or Transfer Frame with a standard pseudo-random sequence.

10.2.2 If the pseudo-randomizer is used, on the sending end it shall be applied to the Codeblock, Codeword, or Transfer Frame after Reed-Solomon, Turbo, or LDPC encoding (if any of these are used), but before convolutional encoding (if used). On the receiving end, it shall be applied to de-randomize the data after convolutional decoding (if used) and codeblock or codeword synchronization but before Reed-Solomon, Turbo, or LDPC decoding (if any of these are used).

NOTE – The configuration at the sending end is shown in figure 10-1.

NOTE – Performance for only the above block lengths (i.e., Transfer Frame lengths) has been validated by CCSDS and approved for use (values are in octets).

11.8 CASE 6: LDPC APPLIED TO A TRANSFER FRAME (SECTION 7)

11.8.1 The Transfer Frame lengths must match the information block lengths for the selected LDPC code.

~~NOTE – The LDPC Codes specified in section 7 of this Recommended Standard are block codes.~~

11.8.2 When the rate-7/8 LDPC code is used, the only allowable Transfer Frame length is 892 octets.

11.8.3 When the 1/2-, 2/3-, and 4/5-rate LDPC codes are used, the allowable Transfer Frame lengths are 128 octets, 512 octets, or 2048 octets.

11.9 CASE 7: LDPC APPLIED TO A STREAM OF CADUS (SECTION 8)

When LDPC coding (of a stream of CADUs) is used, the allowable Transfer Frame length is up to a maximum of 2048 octets.

Table 12-1: Managed Parameters for Selected Options

Managed Parameter	Allowed Values
Randomizer	Present/Absent
Coding Method	None Convolutional Reed-Solomon Concatenated Code Turbo LDPC coding (of a Transfer Frame) LDPC coding (of a stream of CADUs)

12.4 MANAGED PARAMETERS FOR CONVOLUTIONAL CODE

The managed parameters for convolutional code shall be those specified in table 12-2.

Table 12-2: Managed Parameters for Convolutional Code

Managed Parameter	Allowed Values
Code rate (*r*)	1/2, 2/3, 3/4, 5/6, 7/8

12.5 MANAGED PARAMETERS FOR REED-SOLOMON CODE

The managed parameters for Reed-Solomon code shall be those specified in table 12-3.

Table 12-3: Managed Parameters for Reed-Solomon Code

Managed Parameter	Allowed Values
Error Correction Capability (*E*, symbols)	8, 16
Interleaving Depth (*I*)	1, 2, 3, 4, 5, 8
Virtual Fill Length (*Q*, symbols)	Integer

12.6 MANAGED PARAMETERS FOR TURBO CODE

The managed parameters for Turbo code shall be those specified in table 12-4.

Table 12-4: Managed Parameters for Turbo Code

Managed Parameter	Allowed Values
Nominal Code Rate (*r*)	1/2, 1/3, 1/4, 1/6
Information Block Length (*k*, bits)	1784, 3568, 7136, 8920

12.7 MANAGED PARAMETERS FOR LOW-DENSITY PARITY-CHECK ~~CODE~~CODING FOR A TRANSFER FRAME

The managed parameters for LDPC ~~code~~coding for a Transfer Frame shall be those specified in table 12-5.

Table 12-5: Managed Parameters for Low-Density Parity-Check Code

Managed Parameter	Allowed Values
Code Rate (*r*)	1/2, 2/3, 4/5, 7/8
Information Block Length (*k*, bits)	7136 (if *r*=7/8) 1024, 4096, 16384 (if *r*=1/2, 2/3, or 4/5)

12.8 MANAGED PARAMETERS FOR LOW-DENSITY PARITY-CHECK CODING OF A STREAM OF CADUS

The managed parameters for LDPC coding for a stream of CADUs shall be those specified in table 12-6.

Table 12-6: Managed Parameters for Low-Density Parity-Check Code

Managed Parameter	Allowed Values
Code Rate (*r*)	1/2, 2/3, 4/5, 7/8
Slice length (i.e., Information Block Length [*k*, bits])	7136 (if *r*=7/8) 1024, 4096, 16384 (if *r*=1/2, 2/3, or 4/5)
CSM Length (bits)	32 (if *r*=7/8), 64 (if *r*=1/2, 2/3, or 4/5)
LDPC Codeblock Length (number of codewords)	m = 1, 2, 3, 4, 5, 6, 7, 8

NOTE – For LDPC coding for a stream of CADUs,

- the codeword length *n* is determined by the selected code rate, and
- the CSM length is determined by the selected code rate.

12.9 MANAGED PARAMETERS FOR FRAME SYNCHRONIZATION

The managed parameters for frame synchronization shall be those specified in table 12-7.

Table 12-7: Managed Parameters for Frame Synchronization

Managed Parameter	Allowed Values
Transfer Frame Length (bits)	Integer
ASM Length (bits)	32, 64, 96, 128, 192

NOTE – The ASM length is determined by the selected coding schemes.

ANNEX A

SERVICE

(NORMATIVE)

A1 OVERVIEW

A1.1 BACKGROUND

This annex provides service definition in the form of primitives, which present an abstract model of the logical exchange of data and control information between the service provider and the service user. The definitions of primitives are independent of specific implementation approaches.

The parameters of the primitives are specified in an abstract sense and specify the information to be made available to the user of the primitives. The way in which a specific implementation makes this information available is not constrained by this specification. In addition to the parameters specified in this annex, an implementation can provide other parameters to the service user (e.g., parameters for controlling the service, monitoring performance, facilitating diagnosis, and so on).

A2 OVERVIEW OF THE SERVICE

The TM Synchronization and Channel Coding provides unidirectional (one way) transfer of a sequence of fixed-length TM or AOS Transfer Frames at a constant frame rate over a Physical Channel across a space link, with optional error detection/correction.

Only one user can use this service on a Physical Channel~~, and Transfer Frames from different users are not multiplexed together within one Physical Channel~~.

A3 SERVICE PARAMETERS

A3.1 FRAME

A3.1.1 The Frame parameter is the service data unit of this service and shall be either a TM Transfer Frame defined in reference [1] or an AOS Transfer Frame defined in reference [2].

A3.1.2 The length of any Transfer Frame transferred on a Physical Channel must be the same, and is established by management.

ANNEX D

ACRONYMS AND TERMS

(INFORMATIVE)

D1 INTRODUCTION

This annex lists key acronyms and terms that are used throughout this Recommended Standard to describe synchronization and channel coding.

D2 ACRONYMS

AOS	Advanced Orbiting Systems
ASM	Attached Sync Marker
CADU	Channel Access Data Unit
CCSDS	Consultative Committee For Space Data Systems
CSM	Code Sync Marker
FECF	Frame Error Control Field
GF	Galois Field
LDPC	Low-Density Parity-Check
MSB	Most Significant Bit
NRZ-L	Non-Return-to-Zero-Level
NRZ-M	Non-Return-to-Zero-Mark
OSI	Open Systems Interconnection
QPSK	Quadrature Phase Shift Keying
R-S	Reed-Solomon
SANA	Space Assigned Numbers Authority
TC	Telecommand
TCM	Trellis Coded Modulation
TM	Telemetry
VCDU	Virtual Channel Data Unit

D3 TERMS

block encoding: A one-to-one transformation of sequences of length *k* of elements of a source alphabet to sequences of length *n* of elements of a code alphabet, $n>k$.

Synchronization and Channel Coding Sublayer: That sublayer of the Data Link Layer used by CCSDS space link protocols which uses a prescribed coding technique to reliably transfer Transfer Frames through the potentially noisy Physical Layer.

channel symbol: The unit of output of the innermost encoder.

circulant: In LDPC coding, a square matrix with binary entries, where each row is a one-entry right cyclic shift of the preceding row.

~~**Codeblock**: The aggregation of *I* codewords, where *I* is the interleaving depth. In this document, the term Codeblock is used for R-S coding. If *I*=1, the terms Codeblock and Codeword are used interchangeably.~~

codeblock: The aggregation of *one or more* codewords. In this document, the term codeblock is used for R-S coding and for LDPC coding. An R-S codeblock is the aggregation of *I* codewords, where *I* is the interleaving depth. An LDPC codeblock is the aggregation of *m* codewords. If *I*=1 or m=1, the terms codeblock and codeword are used interchangeably.

code rate: The average ratio of the number of binary digits at the input of an encoder to the number of binary digits at its output.

codeword: In a block code, one of the sequences in the range of the one-to-one transformation (see **block encoding**). A codeword of an (*n*,*k*) block code is a sequence of *n* channel symbols which are produced by encoding a sequence of *k* information symbols.

concatenation: The use of two or more codes to process data sequentially with the output of one encoder used as the input of the next.

connection vector (forward): In convolutional and Turbo coding, a vector used to specify one of the parity checks to be computed by the shift register(s) in the encoder. For a shift register with *s* stages, a connection vector is an *s*-bit binary number. A bit equal to 'one' in position *i* (counted from the left) indicates that the output of the *i*th stage of the shift register is to be used in computing that parity check.

connection vector (backward): In Turbo coding, a vector used to specify the feedback to the shift registers in the encoder. For a shift register with *s* stages, a backward connection vector is an *s*-bit binary number. A bit equal to 'one' in position *i* (counted from the left) indicates that the output of the *i*th stage of the shift register is to be used in computing the feedback value, except for the leftmost bit which is ignored.

constraint length: In convolutional coding, the number of consecutive input bits that are needed to determine the value of the output symbols at any time.

ANNEX E

INFORMATIVE REFERENCES

(INFORMATIVE)

~~[E1] *Procedures Manual for the Consultative Committee for Space Data Systems*. CCSDS A00.0-Y-9. Yellow Book. Issue 9. Washington, D.C.: CCSDS, November 2003.~~

[E1] *Organization and Processes for the Consultative Committee for Space Data Systems*. Issue 4. CCSDS Record (Yellow Book), CCSDS A02.1-Y-4. Washington, D.C.: CCSDS, April 2014.

[E2] *Telemetry Channel Coding*. Issue 6-S. Recommendation for Space Data System Standards (Historical), CCSDS 101.0-B-6-S. Washington, D.C.: CCSDS, (October 2002) August 2005.

[E3] *Advanced Orbiting Systems, Networks and Data Links: Architectural Specification*. Issue 3-S. Recommendation for Space Data System Standards (Historical), CCSDS 701.0-B-3-S. Washington, D.C.: CCSDS, (June 2001) August 2005.

[E4] M. Perlman and J. J. Lee. *Reed-Solomon Encoders—Conventional vs. Berlekamp's Architecture*. JPL Publication 82-71. Pasadena, California: JPL, December 1, 1982.

[E5] ~~*Mission Profiles for TM Synchronization and Channel Coding*. Proposed Recommendation for Space Data System Practices, CCSDS 131.4-W-0. White Book. Issue 0. Washington, D.C.: CCSDS, Proposed.~~*TM Channel Coding Profiles*. Issue 1. Recommendation for Space Data System Practices (Magenta Book), CCSDS 131.4-M-1. Washington, D.C.: CCSDS, July 2011.

[E6] *Flexible Advanced Coding and Modulation Scheme for High Rate Telemetry Applications*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 131.2-B-1. Washington, D.C.: CCSDS, March 2012.

[E7] *CCSDS Space Link Protocols over ETSI DVB-S2 Standard*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 131.3-B-1. Washington, D.C.: CCSDS, March 2013.

NOTE – Normative references are listed in 1.7.

Table F-1: Equivalence of Representations[1,2]

POWER	POLY IN ALPHA	$\ell_{01234567}$	POWER	POLY IN ALPHA	$\ell_{01234567}$
*	00000000	00000000	31	11001101	01111010
0	00000001	01111011	32	00011101	10011110
1	00000010	10101111	33	00111010	00111111
2	00000100	10011001	34	01110100	00011100
3	00001000	11111010	35	11101000	01110100
4	00010000	10000110	36	01010111	00100100
5	00100000	11101100	37	10101110	10101101
6	01000000	11101111	38	11011011	11001010
7	10000000	10001101	39	00110001	00010001
8	10000111	11000000	40	01100010	10101100
9	10001001	00001100	41	11000100	11111011
10	10010101	11101001	42	00001111	10110111
11	10101101	01111001	43	00011110	01001010
12	11011101	11111100	44	00111100	00001001
13	00111101	01110010	45	01111000	01111111
14	01111010	11010000	46	11110000	00001000
15	11110100	10010001	47	01100111	01001110
16	01101111	10110100	48	11001110	10101110
17	11011110	00101000	49	00011011	10101000
18	00111011	01000100	50	00110110	01011100
19	01110110	10110011	51	01101100	01100000
20	11101100	11101101	52	11011000	00011110
21	01011111	11011110	53	00110111	00100111
22	10111110	00101011	54	01101110	11001111
23	11111011	00100110	55	11011100	10000111
24	01110001	11111110	56	00111111	11011101
25	11100010	00100001	57	01111110	01001001
26	01000011	00111011	58	11111100	01101011
27	10000110	10111011	59	01111111	00110010
28	10001011	10100011	60	11111110	11000100
29	10010001	01110000	61	01111011	10101011
30	10100101	10000011	62	11110110	00111110

1 From table 4 of reference [E4]. Note: Coefficients of the 'Polynomial in Alpha' column are listed in descending powers of α, starting with α^7.

2 The underlined entries correspond to values with exactly one non-zero element and match a row in the matrix.

ANNEX H

CHANGES FROM REFERENCES [E2] AND [E3]

(INFORMATIVE)

H1 GENERAL

Part of this Recommended Standard was developed from the specifications regarding synchronization and channel coding in older CCSDS Recommended Standards (references [E2] and [E3]), but a few technical specifications in references [E2] and [E3] have been changed in order to define all Space Data Link Protocols in a unified way. These technical changes are described in H2. Also, some technical terms in references [E2] and [E3] have been changed in order to unify the terminology used in all the CCSDS Recommended Standards that define space link protocols, as well as to define these schemes as general communications schemes. These terminology changes are listed in H3.

H2 TECHNICAL CHANGES

H2.1 PARAMETERS ASSOCIATED WITH TRANSFER FRAME LENGTH

In references [E2] and [E3], the periods during which the value of parameters are fixed are not consistently specified. In this Recommended Standard, any parameter associated with the length of the Transfer Frame is fixed for a Mission Phase on a particular Physical Channel.

H2.2 TRANSFER FRAME LENGTHS

The constraints on Virtual Channel Data Unit (VCDU) (AOS Transfer Frame) lengths specified in reference [E3] were different from those on TM Transfer Frame lengths specified in reference [E2]. In this Recommended Standard, the same constraints are applied to both types of Transfer Frames.

H3 TERMINOLOGY CHANGES

Tables H-1 and H-2 list the terms that have been changed from references [E2] and [E3], respectively.

~~Table H-1: Terms That Have Been Changed from Reference~~ [E2]

~~Terms Used in Reference~~ [E2]	~~Terms Used in This Recommended Standard~~
~~Telemetry Transfer Frame~~	~~TM Transfer Frame~~

~~Table H-2: Terms That Have Been Changed from Reference~~ [E3]

~~Terms Used in Reference~~ [E3]	~~Terms Used in This Recommended Standard~~
~~PCA_PDU~~	~~Channel Symbols~~
~~Virtual Channel Data Unit (VCDU)~~	~~AOS Transfer Frame~~