The Consultative Committee for Space Data Systems

Recommendation for Space Data System Standards

VARIABLE CODED MODULATION PROTOCOL

RECOMMENDED STANDARD

CCSDS 431.1-B-1

BLUE BOOK
February 2021

The Consultative Committee for Space Data Systems

Recommendation for Space Data System Standards

VARIABLE CODED MODULATION PROTOCOL

RECOMMENDED STANDARD

CCSDS 431.1-B-1

BLUE BOOK

February 2021

AUTHORITY

Issue:	Recommended Standard, Issue 1
Date:	February 2021
Location:	Washington, DC, USA

This document has been approved for publication by the Management Council of the Consultative Committee for Space Data Systems (CCSDS) and represents the consensus technical agreement of the participating CCSDS Member Agencies. The procedure for review and authorization of CCSDS documents is detailed in *Organization and Processes for the Consultative Committee for Space Data Systems* (CCSDS A02.1-Y-4), and the record of Agency participation in the authorization of this document can be obtained from the CCSDS Secretariat at the email address below.

This document is published and maintained by:

CCSDS Secretariat
National Aeronautics and Space Administration
Washington, DC, USA
Email: secretariat@mailman.ccsds.org

STATEMENT OF INTENT

The Consultative Committee for Space Data Systems (CCSDS) is an organization officially established by the management of its members. The Committee meets periodically to address data systems problems that are common to all participants, and to formulate sound technical solutions to these problems. Inasmuch as participation in the CCSDS is completely voluntary, the results of Committee actions are termed **Recommended Standards** and are not considered binding on any Agency.

This **Recommended Standard** is issued by, and represents the consensus of, the CCSDS members. Endorsement of this **Recommendation** is entirely voluntary. Endorsement, however, indicates the following understandings:

- o Whenever a member establishes a CCSDS-related **standard**, this **standard** will be in accord with the relevant **Recommended Standard**. Establishing such a **standard** does not preclude other provisions which a member may develop.
- o Whenever a member establishes a CCSDS-related **standard**, that member will provide other CCSDS members with the following information:
  - -- The **standard** itself.
  - -- The anticipated date of initial operational capability.
  - -- The anticipated duration of operational service.
- o Specific service arrangements shall be made via memoranda of agreement. Neither this **Recommended Standard** nor any ensuing **standard** is a substitute for a memorandum of agreement.

No later than five years from its date of issuance, this **Recommended Standard** will be reviewed by the CCSDS to determine whether it should: (1) remain in effect without change; (2) be changed to reflect the impact of new technologies, new requirements, or new directions; or (3) be retired or canceled.

In those instances when a new version of a **Recommended Standard** is issued, existing CCSDS-related member standards and implementations are not negated or deemed to be non-CCSDS compatible. It is the responsibility of each member to determine when such standards or implementations are to be modified. Each member is, however, strongly encouraged to direct planning for its new standards and implementations towards the later version of the Recommended Standard.

FOREWORD

This document is a CCSDS Recommended Standard for using Variable Coded Modulation (VCM) together with the CCSDS recommended channel codes described in references [1], [2], and [4].

Through the process of normal evolution, it is expected that expansion, deletion, or modification of this document may occur. This Recommended Standard is therefore subject to CCSDS document management and change control procedures, which are defined in the *Organization and Processes for the Consultative Committee for Space Data Systems* (CCSDS A02.1-Y-4). Current versions of CCSDS documents are maintained at the CCSDS Web site:

http://www.ccsds.org/

Questions relating to the contents or status of this document should be sent to the CCSDS Secretariat at the email address indicated on page i.

At time of publication, the active Member and Observer Agencies of the CCSDS were:

Member Agencies

- Agenzia Spaziale Italiana (ASI)/Italy.
- Canadian Space Agency (CSA)/Canada.
- Centre National d'Etudes Spatiales (CNES)/France.
- China National Space Administration (CNSA)/People's Republic of China.
- Deutsches Zentrum für Luft- und Raumfahrt (DLR)/Germany.
- European Space Agency (ESA)/Europe.
- Federal Space Agency (FSA)/Russian Federation.
- Instituto Nacional de Pesquisas Espaciais (INPE)/Brazil.
- Japan Aerospace Exploration Agency (JAXA)/Japan.
- National Aeronautics and Space Administration (NASA)/USA.
- UK Space Agency/United Kingdom.

Observer Agencies

- Austrian Space Agency (ASA)/Austria.
- Belgian Science Policy Office (BELSPO)/Belgium.
- Central Research Institute of Machine Building (TsNIIMash)/Russian Federation.
- China Satellite Launch and Tracking Control General, Beijing Institute of Tracking and Telecommunications Technology (CLTC/BITTT)/China.
- Chinese Academy of Sciences (CAS)/China.
- China Academy of Space Technology (CAST)/China.
- Commonwealth Scientific and Industrial Research Organization (CSIRO)/Australia.
- Danish National Space Center (DNSC)/Denmark.
- Departamento de Ciência e Tecnologia Aeroespacial (DCTA)/Brazil.
- Electronics and Telecommunications Research Institute (ETRI)/Korea.
- European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)/Europe.
- European Telecommunications Satellite Organization (EUTELSAT)/Europe.
- Geo-Informatics and Space Technology Development Agency (GISTDA)/Thailand.
- Hellenic National Space Committee (HNSC)/Greece.
- Hellenic Space Agency (HSA)/Greece.
- Indian Space Research Organization (ISRO)/India.
- Institute of Space Research (IKI)/Russian Federation.
- Korea Aerospace Research Institute (KARI)/Korea.
- Ministry of Communications (MOC)/Israel.
- Mohammed Bin Rashid Space Centre (MBRSC)/United Arab Emirates.
- National Institute of Information and Communications Technology (NICT)/Japan.
- National Oceanic and Atmospheric Administration (NOAA)/USA.
- National Space Agency of the Republic of Kazakhstan (NSARK)/Kazakhstan.
- National Space Organization (NSPO)/Chinese Taipei.
- Naval Center for Space Technology (NCST)/USA.
- Netherlands Space Office (NSO)/The Netherlands.
- Research Institute for Particle & Nuclear Physics (KFKI)/Hungary.
- Scientific and Technological Research Council of Turkey (TUBITAK)/Turkey.
- South African National Space Agency (SANSA)/Republic of South Africa.
- Space and Upper Atmosphere Research Commission (SUPARCO)/Pakistan.
- Swedish Space Corporation (SSC)/Sweden.
- Swiss Space Office (SSO)/Switzerland.
- United States Geological Survey (USGS)/USA.

DOCUMENT CONTROL

Document	Title	Date	Status
CCSDS 431.1-B-1	Variable Coded Modulation Protocol, Recommended Standard, Issue 1	February 2021	Original issue

CONTENTS

CONTENTS (continued)

1 INTRODUCTION

1.1 BACKGROUND

Variable Coded Modulation (VCM) is a method to rapidly switch the channel coding and modulation used during a communications session. After a transmission using one coded modulation, another coded modulation may be used to match dynamic link conditions in near real time. Such dynamic conditions may arise, for example, because of changes in geometry, weather, interference, launch plumes, and scintillation. With judicious choice of the coded modulations over time, excess margin can be reduced and total data throughput increased.

VCM is a protocol that is compatible with a wide variety of channel codes and modulations. Given a numbered list of coded modulations, a VCM protocol provides a mechanism to transition between them in a way that is understandable to the receiver.

CCSDS has three Recommended Standards that define channel codes, and one Recommended Standard that defines modulations for use on the space-to-Earth link. The first of the existing coding standards includes convolutional codes, Reed-Solomon codes, concatenated convolutional and Reed-Solomon codes, turbo codes, and Low-Density Parity-Check (LDPC) codes (reference [1]), to be used with recommended modulations (reference [5]). No VCM protocol is specified in references [1] and [5]. A second Recommended Standard specifies a set of Serially Concatenated Convolutional Codes (SCCCs), together with a set of modulations and a VCM protocol (reference [2]). A third Recommended Standard specifies a mechanism to communicate CCSDS Transfer Frames using an existing ETSI standard for Digital Video Broadcasting by Satellites (DVB-S2), which uses BCH codes concatenated with LDPC codes (references [3] and [4]). The DVB-S2 standard (reference [4]), and consequently the CCSDS standard (reference [3]), specifies a VCM protocol as well as a method for the receiver to monitor quality-of-reception parameters and to communicate this information back to the transmitter, as part of an Adaptive Coded Modulation (ACM) protocol.

1.2 PURPOSE AND SCOPE

The purpose of this Recommended Standard is to specify various combinations of coding and modulations in references [1], [2], [4], and [5], that can operate under the VCM protocol defined in references [2] and [4]. This enables, for example, some of the CCSDS recommended channel codes (reference [1]) and modulations (reference [5]) to be used with the CCSDS VCM protocol. The main applications are for space missions that need high data rate telemetry, or that operate in dynamic environments.

When VCM is used, the use is to follow this VCM Recommended Standard, which is compatible with references [2] and [3]. This Recommended Standard does not require all transmissions to use a VCM protocol. For example, CCSDS telemetry codes in reference [1] and the modulations in reference [5] may be used without a VCM protocol.

1.3 NOMENCLATURE

1.3.1 NORMATIVE TEXT

The following conventions apply throughout this Specification:

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.

1.3.2 INFORMATIVE TEXT

In the normative sections of this document, informative text is set off from the normative specifications either in notes or under one of the following subsection headings:

– Overview;

– Background;

– Rationale;

– Discussion.

1.4 DEFINITIONS

1.4.1 DEFINITIONS FROM THE OPEN SYSTEM INTERCONNECTION (OSI) BASIC REFERENCE MODEL

This Recommended Standard makes use of a number of terms defined in reference [C1]. The use of those terms in this Recommended Standard is to be understood in a generic sense, i.e., in the sense that those terms are generally applicable to any of a variety of technologies that provide for the exchange of information between real systems. Those terms are:

a) Data Link Layer;

b) Physical Layer.

1.4.2 DEFINITIONS FROM TM CHANNEL CODING (REFERENCE [1])

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.

synchronization-marked transfer frame, SMTF: A data unit consisting of an Attached Synchronization Marker (ASM) followed by a Transfer Frame.

channel access data unit, CADU: A data unit consisting of either an ASM or a Code Synchronization Marker (CSM) followed by a Transfer Frame, a codeword, or a codeblock, depending on the coding scheme in use.

1.4.3 TERMS DEFINED IN THIS DOCUMENT

variable coded modulation, VCM: A method to adapt the transmission scheme to channel conditions following a predetermined schedule.

1.5 CONVENTIONS

In this document, the following convention is used to identify each bit in an *N*-bit field. The first bit in the field to be transmitted (i.e., the most left justified when drawing a figure) is defined to be 'Bit 0', the following bit is defined to be 'Bit 1', and so on up to 'Bit *N*−1'. When the field is used to express a binary value (such as a counter), the Most Significant Bit (MSB) shall be the first transmitted bit of the field, i.e., 'Bit 0' (see figure 1-1).

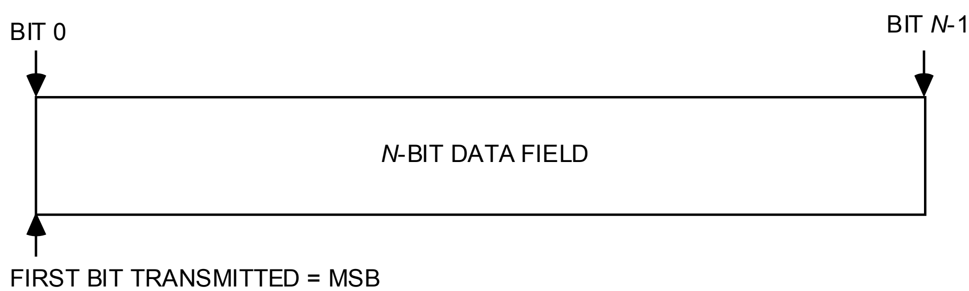

Figure 1-1: Bit Numbering Convention

The convention for matrices differs from that for bit fields. Matrices are indexed beginning with the number '1'.

In accordance with standard data-communications practice, data fields are often grouped into 8-bit 'words' which conform to the above convention. Throughout this specification, such an 8-bit word is called an 'octet'. The numbering for octets within a data structure starts with '0'.

1.6 REFERENCES

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

[1] *TM Synchronization and Channel Coding*. Issue 3. Recommendation for Space Data System Standards (Blue Book), CCSDS 131.0-B-3. Washington, D.C.: CCSDS, September 2017.

[2] *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.

[3] *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.

[4] *Digital Video Broadcasting (DVB); Second Generation Framing Structure, Channel Coding and Modulation Systems for Broadcasting, Interactive Services, News Gathering and Other Broadband Satellite Applications; Part 2: DVB-S2 Extensions (DVB-S2X)*. ETSI EN 302 307-2 V1.1.1 (2014-10). Sophia-Antipolis: ETSI, 2014.

[5] *Radio Frequency and Modulation Systems—Part 1: Earth Stations and Spacecraft*. Issue 31. Recommendations for Space Data System Standards (Blue Book), CCSDS 401.0-B-31. Washington, D.C.: CCSDS, February 2021.

2 OVERVIEW

Figure 2-1 illustrates the relationship of this Recommended Standard to the Open Systems Interconnection reference model (reference [C1]). Two sublayers of the Data Link Layer are defined for CCSDS space link protocols. The TM, AOS, and USLP Space Data Link Protocols specified in references [C2], [C3], and [C5], respectively, correspond to the data link protocol sublayer, and provide functions for transferring data using the protocol data unit called the Transfer Frame. The synchronization and channel coding sublayer provides methods of synchronization and channel coding for transferring Transfer Frames over a space link while the Physical Layer provides the RF and modulation methods for transferring a stream of bits over a space link in a single direction.

This Recommended Standard covers functions in both the Synchronization and Channel Coding Sublayer and the Physical Layer.

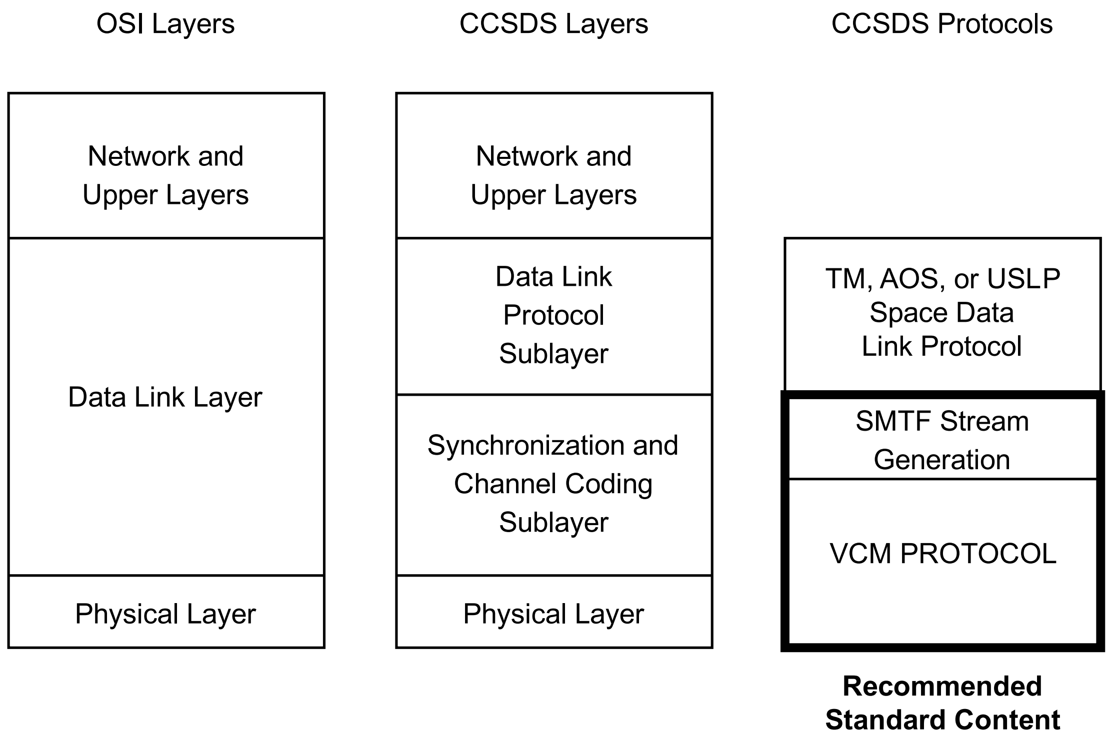

Figure 2-1: Relationship with OSI Layers

3 VARIABLE CODED MODULATION PROTOCOL

NOTE – Implementers are cautioned to consult references [2] and [3] for the latest specification of the VCM protocols to be used with SCCC and DVB-S2 codes defined in those references.

3.1 DISCUSSION—SLICER AND PLFRAME STRUCTURE

The VCM protocol operates by taking CCSDS Transfer Frames as input, adding an ASM to form SMTFs, slicing the SMTFs asynchronously into encoder-input-sized blocks, encoding them with a channel code, producing modulation symbols corresponding to the encoded block, prepending a Physical Layer (PL) frame (PLFRAME) header, and optionally inserting pilot symbols within the codeword modulation symbols of the non-header part of the PLFRAME. This structure is shown in figure 3-1. Transmission consists of a sequence of PLFRAMEs transmitted contiguously without gaps.

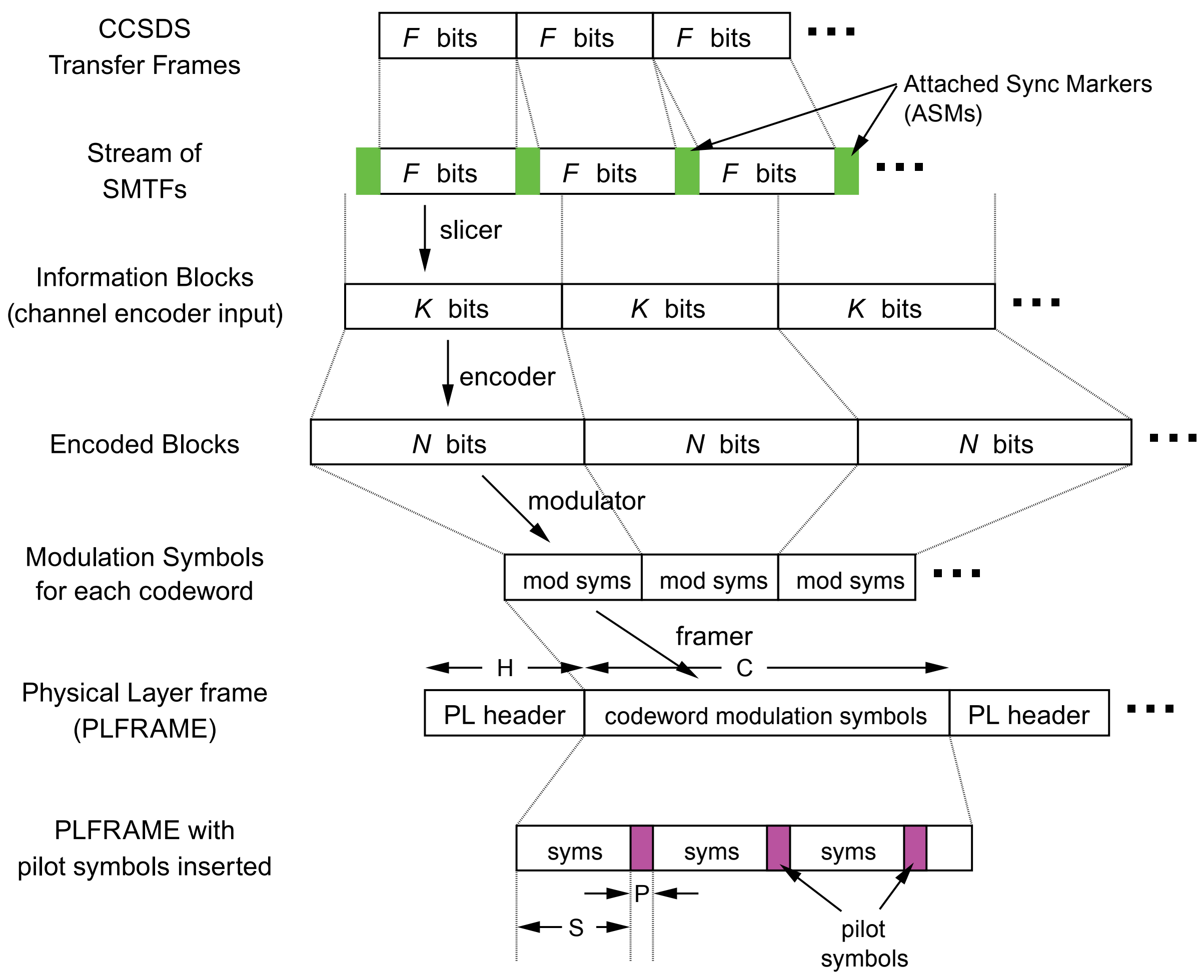

Figure 3-1: Structure of the PLFRAME of the VCM Protocol

NOTE – The structure shown in figure 3-1 is consistent with the SCCC VCM protocol (reference [2]), which is the basis for the Type 1 VCM protocol specified below, and with the DVB-S2 VCM protocol (reference [4]), which is the basis for the Type 2 VCM protocol specified below. It is important to note that what is referred to here as SMTF is called CADU in references [2] and [3].

3.2 INPUT

3.2.1 FRAME TYPE

The VCM system shall accept fixed-length Transfer Frames from the Data Link Protocol sublayer.

NOTE – These can be TM, AOS, or USLP Transfer Frames whose contents are not checked by the VCM system.

3.2.2 FRAME LENGTH

3.2.2.1 TM and AOS Transfer Frames

TM and AOS Transfer Frames length shall vary between the following minimum and maximum values: 223 octets (1784 bits) and 2048 octets (16384 bits).

3.2.2.2 USLP Transfer Frames

USLP Transfer Frames length shall vary between the following minimum and maximum values: 223 octets (1784 bits) and 65536 octets (524288 bits).

NOTE – As the VCM system is not expected to check the frame type, it is up to user to comply with the given limits.

3.3 SPECIFICATION

The VCM protocol shall be either a Type 1 VCM protocol or a Type 2 VCM protocol controlled by a managed parameter. The Type of the VCM protocol determines:

a) H, the length of the PLFRAME header;

b) C, the number of codeword modulation symbols present in the PLFRAME;

c) S, the number of codeword modulation symbols between pilot symbol blocks; and

d) P, the number of modulation symbols present in each optional pilot symbol block.

NOTE – H, C, S, and P are illustrated in figure 3-1. The values of H, C, S, and P for Types 1 and 2 VCM protocols are shown in table 3-1.

Table 3-1: Parameter Values for Type 1 and Type 2 VCM Protocols

VCM Type	Codes	H (symbols)	C (symbols)	S (symbols)	P (symbols)
Type 1	TM (table 3-2)	320 (if frame descriptor transmitted) or 256 (otherwise)	Varies (16 codewords)	540	16
	SCCC (table 3-3)	320	8100 × 16 (16 codewords)		
Type 2	TM (table 3-2)	90 (if frame descriptor transmitted) or 26 (otherwise)	Varies (1 codeword)	1440	36
	DVB-S2 (table 3-4)	90	Varies (1 codeword)		

3.3.1 TYPE 1 VCM

3.3.1.1 Allowed VCM Mode Tables

As indicated in table 3-1, Type 1 VCM shall be used with the VCM mode table shown in table 3-2 (i.e., a subset of the TM codes—see reference [1]) or with the VCM mode table shown in table 3-3 (i.e., SCCC codes—see reference [2]).

3.3.1.2 Encoder Input and Output Length

The information block length, shown as K in figure 3-1, shall be an input length indicated in a row of the VCM mode table shown in table 3-2 or table 3-3. The codeword (output) length, shown as N in in figure 3-1, is defined in references [1] and [2], respectively.

3.3.1.3 Encoder Output Padding

When CCSDS codes of reference [1] are used as given in the VCM mode table 3-2, each codeword shall be 0-padded at the end, if necessary, so that the overall length is a multiple of the modulation order for the selected VCM mode.

NOTES

1 The modulation order can be mapped to the selected modulation as follows: 2 = QPSK, 3 = 8-PSK, 4 = 16-APSK, 5 = 32-APSK, and 6 = 64-APSK.

2 For example, if mode 12 is being used from table 3-2, with input length 1024, then each codeword of length 2048 is padded with one zero to form 2049 symbols, which is a multiple of 3 that maps into 683 8-PSK symbols.

3.3.1.4 Type 1 PLFRAME Header

3.3.1.4.1

In Type 1 VCM, when SCCC codes given in the VCM mode table 3-3 are used, the PLFRAME header shall be H = 320 π/2 BPSK symbols, as specified in reference [2].

3.3.1.4.2

In Type 1 VCM, when CCSDS TM codes are used as given in the VCM mode table 3-2, the PLFRAME header shall be either H = 256 or H = 320 symbols.

NOTE – A managed parameter in table 4-1 states whether the Frame Descriptor (FD) portion of the frame header is transmitted or omitted.

3.3.1.5 PLFRAME Payload

In Type 1 VCM, the PLFRAME, excluding the header, shall be C modulation symbols corresponding to 16 codewords, constructed as specified in reference [2], including the method of bit interleaving described in subsection 4.5 of reference [2] and mapping to the modulation symbols described in subsection 5.2 of reference [2].

NOTE – When SCCC is used as given in the VCM mode table 3-3, each codeword corresponds to 8100 modulation symbols, excluding any pilot symbols. When CCSDS TM codes are used as given in the VCM mode table 3-2, the number of modulation symbols per codeword, C/16, may vary from one PLFRAME to the next, depending on the VCM mode selected. When CCSDS TM codes are used, the interleaving method in reference [2] shall have C/16 rows, instead of 8100.

3.3.1.6 Pilot Insertion

Each PLFRAME, excluding the header, may have pilot symbols inserted, as shown at the bottom of figure 3-1. If insertion of distributed pilot symbols is performed, it shall follow the format specified in figure 3-2, using the parameter values from table 3-1. In case C is a multiple of S, the PLFRAME shall end with pilot symbols.

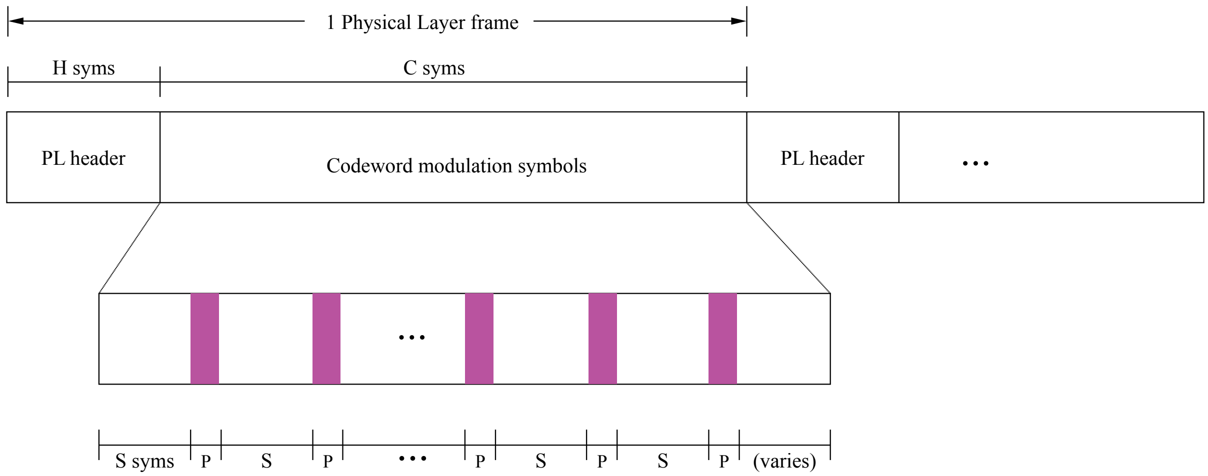

Figure 3-2: Distributed Pilot Pattern

NOTE – When SCCC is used as given in the VCM mode table 3-3, and distributed pilot symbols are used, the PLFRAME ends with pilot symbols, which result is a consequence of 8100 symbols' being a multiple of 540. Otherwise, it may end with codeword modulation symbols.

3.3.1.7 Physical Layer Randomization

The PLFRAME, excluding the header, shall be randomized as described in subsection 5.5 of reference [2]. In case the PLFRAME length (excluding header) has length longer than that PL randomizer sequence (133440 channel symbols), the PL randomizer sequence shall be extended with a periodic replica.

3.3.1.8 Baseband Shaping

The modulation symbols of the PLFRAME shall be shaped as described in section 6 of reference [2].

3.3.2 TYPE 2 VCM

3.3.2.1 Allowed VCM Mode Tables

As indicated in table 3-1, Type 2 VCM must be used with the VCM mode table shown in table 3-2 (i.e., a subset of the TM codes—see reference [1]) or with the VCM mode table shown in table 3-4 (i.e., DVB-S2 codes—see reference [4]).

3.3.2.2 Encoder Input and Output Length

The information block length, shown as *K* in figure 3-1, shall be an input length indicated in a row of the VCM mode table shown in table 3-2 or table 3-4. The codeword (output) length, shown as *N* in in figure 3-1, is defined in references [1] and [4], respectively.

3.3.2.3 Encoder Output Padding

When CCSDS TM codes are used as given in the VCM mode table 3-2, each codeword is 0-padded at the end, if necessary, as specified in 3.3.1.3.

3.3.2.4 Type 2 PLFRAME Header

3.3.2.4.1

In Type 2 VCM, when DVB-S2 codes given in the VCM mode table 3-4 are used, the PLFRAME header shall be H = 90 π/2 BPSK symbols, as specified in reference [4].

3.3.2.4.2

In Type 2 VCM, when CCSDS TM codes are used as given in the VCM mode table 3-2, the PLFRAME header shall be either H = 26 or H = 90 symbols.

NOTE – A managed parameter in table 4-1 states whether the Physical Layer signaling code portion of the PLFRAME header is transmitted or omitted.

3.3.2.5 PLFRAME Payload

In Type 2 VCM, the PLFRAME, excluding the header, shall be C modulation symbols corresponding to one codeword, constructed as specified in reference [4], including the method of bit interleaving described in subsection 5.3.3 of reference [4] and mapping to modulation symbols described in subsection 5.4 of reference [4].

NOTE – Whether DVB-S2 codes are used as given in the VCM mode table 3-4, or CCSDS TM codes are used as given in the VCM mode table 3-2, the codeword section length may vary from one PLFRAME to the next, depending on the VCM mode selected.

3.3.2.6 Pilot Insertion

Pilot symbols may be inserted, as described in 3.3.1.6, using the parameter values from table 3-1.

3.3.2.7 Physical Layer Scrambling

The PLFRAME, excluding the header, shall be scrambled as described in subsection 5.5.4 of reference [4].

3.3.2.8 Baseband Shaping

The modulation symbols of the PLFRAME shall be shaped as described in subsection 5.6 of reference [4].

3.4 VCM MODE TABLES

3.4.1 GENERAL

3.4.1.1 The mode tables in 3.4.2—3.4.4 shall be used to select encoding and modulation for PLFRAME modulation symbols.

3.4.1.2 This Recommended Standard allows various VCM mode tables. The particular VCM mode table being used shall be a managed parameter (see section 4).

3.4.2 VCM MODE TABLE FOR CCSDS TURBO AND LDPC CODES

VCM mode table 3-2, using TM codes defined in reference [1] and modulations defined in reference [5], may be used with either the Type 1 or Type 2 VCM protocol.

NOTE – The TM codes referenced in table 3-2 include turbo codes defined in section 6 of reference [1] and the LDPC codes defined in section 7 of reference [1]. Other processing defined in reference [1], including CSM and pseudo-randomization are not used in the VCM protocol; instead, PLFRAMEs are constructed as shown in figure 3-1.

Table 3-2: VCM Mode Table Corresponding to Reference [1]

VCM Mode	Modulation	Code	Code Rate (Note 1)	Input Length (short) *K* bits (Note 2)	Input Length (long) *K* bits (Note 2)
0	Reserved				
1	BPSK	Turbo	1/6	1784	8920
2	BPSK	Turbo	1/4	1784	8920
3	BPSK	Turbo	1/3	1784	8920
4	BPSK	LDPC	1/2	1024	16384
5	BPSK	LDPC	2/3	1024	16384
6	BPSK	LDPC	4/5	1024	16384
7	BPSK	LDPC	223/255	7136	7136
8	QPSK	LDPC	1/2	1024	16384
9	QPSK	LDPC	2/3	1024	16384
10	QPSK	LDPC	4/5	1024	16384
11	QPSK	LDPC	223/255	7136	7136
12	8-PSK	LDPC	1/2	1024	16384
13	8-PSK	LDPC	2/3	1024	16384
14	8-PSK	LDPC	4/5	1024	16384
15	8-PSK	LDPC	223/255	7136	7136
16	16-APSK	LDPC	1/2	1024	16384
17	16-APSK	LDPC	2/3	1024	16384
18	16-APSK	LDPC	4/5	1024	16384
19	16-APSK	LDPC	223/255	7136	7136
20	32-APSK	LDPC	1/2	1024	16384
21	32-APSK	LDPC	2/3	1024	16384
22	32-APSK	LDPC	4/5	1024	16384
23	32-APSK	LDPC	223/255	7136	7136
24	64-APSK	LDPC	1/2	1024	16384
25	64-APSK	LDPC	2/3	1024	16384
26	64-APSK	LDPC	4/5	1024	16384
27	64-APSK	LDPC	223/255	7136	7136
28	Reserved				
29	Reserved				
30	Reserved				
31	Reserved				

NOTES

1 The turbo codes have a slightly lower code rate than listed, because of the termination bits used at the end of the codeblock.

2 Information block length *K* is discussed in 3.3.1.2 and 3.3.2.2.

3 The ratio of outer circle to inner circle radius to be used in modes 16-27 is defined in reference [5].

3.4.3 VCM MODE TABLE FOR CCSDS SCCC

VCM mode table 3-3 shall be used with the Type 1 VCM Protocol, consistent with the existing specification of codes, modulations, and VCM protocol given in references [2] and [5].

Table 3-3: VCM Mode Table Corresponding to Reference [2]

VCM Mode	Modulation	Code	Code Rate	Input Length *K* bits (Note)
1	QPSK	SCCC	0.36	5758
2	QPSK	SCCC	0.43	6958
3	QPSK	SCCC	0.52	8398
4	QPSK	SCCC	0.61	9838
5	QPSK	SCCC	0.7	11278
6	QPSK	SCCC	0.81	13198
7	8-PSK	SCCC	0.46	11278
8	8-PSK	SCCC	0.54	13198
9	8-PSK	SCCC	0.61	14878
10	8-PSK	SCCC	0.7	17038
11	8-PSK	SCCC	0.79	19198
12	8-PSK	SCCC	0.88	21358
13	16-APSK	SCCC	0.59	19198
14	16-APSK	SCCC	0.66	21358
15	16-APSK	SCCC	0.73	23518
16	16-APSK	SCCC	0.8	25918
17	16-APSK	SCCC	0.87	28318
18	32-APSK	SCCC	0.64	25918
19	32-APSK	SCCC	0.7	28318
20	32-APSK	SCCC	0.76	30958
21	32-APSK	SCCC	0.82	33358
22	32-APSK	SCCC	0.89	35998
23	64-APSK	SCCC	0.69	33358
24	64-APSK	SCCC	0.74	35998
25	64-APSK	SCCC	0.80	38638
26	64-APSK	SCCC	0.84	41038
27	64-APSK	SCCC	0.9	43678
28	Reserved			
29	Reserved			
30	Reserved			
31	Reserved			
NOTE – Information block length *K* is discussed in 3.3.1.2.				

3.4.4 VCM MODE TABLE FOR CCSDS DVB-S2 ENCODING

VCM mode table 3-4 shall be used with the Type 2 VCM Protocol, consistent with the existing specification of codes, modulations, and VCM protocol given in references [3], [4], and [5].

NOTE – In table 3-4, 'DVB-S2 encoding' includes (see figure 1 in reference [4]):

– DVB-S2 baseband header insertion (subsection 5.1.6 in reference [4]);

– DVB-S2 baseband scrambling (subsection 5.2.2 in reference [4]);

– DVB-S2 FEC coding (subsection 5.3 in reference [4]), including:

  - BCH encoding (subsection 5.3.1 in reference [4]);
  - LDPC encoding (subsection 5.3.2 in reference [4]);
  - Bit interleaving (subsection 5.3.3 in reference [4]).

The input length, that is, the length of the information blocks at the input of the 'DVB-S2 encoding' is, in the terminology of references [3] and [4], DFL = K_{bch} − 80 bits.

Table 3-4: VCM Mode Table Corresponding to References [3] and [4]

VCM Mode	Modulation	Code	Code Rate (Note 1)	Input Length (short) *K* bits (Note 2)	Input Length (long) *K* bits (Note 2)
0	DUMMY PLFRAME		0	0	0
1	QPSK	DVB-S2 encoding	1/4	2 992	15 928
2	QPSK	DVB-S2 encoding	1/3	5 152	21 328
3	QPSK	DVB-S2 encoding	2/5	6 232	25 648
4	QPSK	DVB-S2 encoding	1/2	6 952	32 128
5	QPSK	DVB-S2 encoding	3/5	9 472	38 608
6	QPSK	DVB-S2 encoding	2/3	10 552	42 960
7	QPSK	DVB-S2 encoding	3/4	11 632	48 328
8	QPSK	DVB-S2 encoding	4/5	12 352	51 568
9	QPSK	DVB-S2 encoding	5/6	13 072	53 760
10	QPSK	DVB-S2 encoding	8/9	14 152	57 392
11	QPSK	DVB-S2 encoding	9/10	n/a	58 112
12	8-PSK	DVB-S2 encoding	3/5	9 472	38 608
13	8-PSK	DVB-S2 encoding	2/3	10 552	42 960
14	8-PSK	DVB-S2 encoding	3/4	11 632	48 328
15	8-PSK	DVB-S2 encoding	5/6	13 072	53 760
16	8-PSK	DVB-S2 encoding	8/9	14 152	57 392
17	8-PSK	DVB-S2 encoding	9/10	n/a	58 112
18	16-APSK	DVB-S2 encoding	2/3	10 552	42 960
19	16-APSK	DVB-S2 encoding	3/4	11 632	48 328
20	16-APSK	DVB-S2 encoding	4/5	12 352	51 568
21	16-APSK	DVB-S2 encoding	5/6	13 072	53 760
22	16-APSK	DVB-S2 encoding	8/9	14 152	57 392
23	16-APSK	DVB-S2 encoding	9/10	n/a	58 112
24	32-APSK	DVB-S2 encoding	3/4	11 632	48 328
25	32-APSK	DVB-S2 encoding	4/5	12 352	51 568
26	32-APSK	DVB-S2 encoding	5/6	13 072	53 760
27	32-APSK	DVB-S2 encoding	8/9	14 152	57 392
28	32-APSK	DVB-S2 encoding	9/10	n/a	58 112
29	Reserved				
30	Reserved				
31	Reserved				

NOTES

1 The code rate listed is the rate of the LDPC code only; it does not include the BCH code rate. It also does not account for the loss of rate due to the 80-bit baseband header.

2 Information block length *K* is discussed in 3.3.2.2.

4 MANAGED PARAMETERS

4.1 OVERVIEW

In order to conserve bandwidth on the space link, some parameters associated with modulation, synchronization, and channel coding are handled by management rather than by the inline communications protocol. The managed parameters are generally those which tend to be static for long periods of time, and whose change generally signifies a major reconfiguration of the modulation, synchronization, and channel coding systems associated with a particular mission, i.e., parameters that are fixed within a mission phase.

Through the use of a management system, management conveys the required information to the modulation, synchronization, and channel coding systems. In this section, the managed parameters used by systems applying this Recommended Standard are listed. These parameters are defined in an abstract sense and are not intended to imply any particular implementation of a management system.

4.2 MANAGED PARAMETERS FOR VCM PROTOCOL

The managed parameters associated with the VCM Protocol shall conform to the definitions in table 4-1.

Table 4-1: VCM Protocol Managed Parameters

Managed Parameter	Allowed Values
Transfer Frame Length (octets)	Integer: 223 to 65536 octets
VCM protocol type	1, 2
VCM mode table*	Table 3-2, 3-3, or 3-4
Transmission of Frame Descriptor (Type 1), or equivalently, Physical Layer signaling code (Type 2)	Transmitted or not transmitted
Current pilot insertion status	ON, OFF

NOTE – As described in 3.4.2, 3.4.3, and 3.4.4, VCM Type 1 may use table 3-2 or 3-3, and VCM Type 2 may use table 3-2 or 3-4.

ANNEX A

PROTOCOL IMPLEMENTATION CONFORMANCE STATEMENT PROFORMA

(NORMATIVE)

A1 INTRODUCTION

A1.1 OVERVIEW

This annex provides the Protocol Implementation Conformance Statement (PICS) Requirements List (RL) for an implementation of Variable Coded Modulation Protocol (CCSDS 431.1-B-1). The PICS for an implementation is generated by completing the RL in accordance with the instructions below. An implementation claiming conformance must satisfy the mandatory requirements referenced in the RL.

The RL support column in this annex is blank. An implementation's completed RL is called the PICS. The PICS states which capabilities and options have been implemented. The following can use the PICS:

– the implementer, as a checklist to reduce the risk of failure to conform to the standard through oversight;

– a supplier or potential acquirer of the implementation, as a detailed indication of the capabilities of the implementation, stated relative to the common basis for understanding provided by the standard PICS proforma;

– a user or potential user of the implementation, as a basis for initially checking the possibility of interworking with another implementation (it should be noted that, while interworking can never be guaranteed, failure to interwork can often be predicted from incompatible PICSes);

– a tester, as the basis for selecting appropriate tests against which to assess the claim for conformance of the implementation.

A1.2 ABBREVIATIONS AND CONVENTIONS

The RL consists of information in tabular form. The status of features is indicated using the abbreviations and conventions described below.

Item Column

The item column contains sequential numbers for items in the table.

Description Column

The description column contains a brief description of the item. It implicitly means 'Is this item supported by the implementation?'

Reference Column

The reference column indicates the relevant subsection of *Variable Coded Modulation Protocol*, CCSDS 431.1-B-1 (this document).

Status Column

The status column uses the following notations:

M	mandatory.
O	optional.
C:<status>	indicates that the status applies for the given subordinate item when the parent item is supported, and is not applicable otherwise.
1+	One or more of the allowed values must be supported
N/A	not applicable.

Support Column Symbols

The support column is to be used by the implementer to state whether a feature is supported by entering Y, N, or N/A, indicating:

Y	Yes, supported by the implementation.
N	No, not supported by the implementation.
N/A	Not applicable.

The support column should also be used, when appropriate, to enter values supported for a given capability.

A1.3 INSTRUCTIONS FOR COMPLETING THE RL

An implementer shows the extent of compliance to the Recommended Standard by completing the RL; that is, the state of compliance with all mandatory requirements and the options supported are shown. The resulting completed RL is called a PICS. The implementer shall complete the RL by entering appropriate responses in the support or values supported column, using the notation described in A1.2. If a conditional requirement is inapplicable, N/A should be used. If a mandatory requirement is not satisfied, exception information must be supplied by entering a reference X*i*, where *i* is a unique identifier, to an accompanying rationale for the noncompliance.

A2 PICS PROFORMA FOR VARIABLE CODED MODULATION PROTOCOL (CCSDS 431.1-B-1)

A2.1 GENERAL INFORMATION

A2.1.1 Identification of PICS

Date of Statement (DD/MM/YYYY)	
PICS serial number	
System Conformance statement cross-reference	

A2.1.2 Identification of Implementation Under Test (IUT)

Implementation Name	
Implementation Version	
Special Configuration	
Other Information	

A2.1.3 Identification of Supplier

Supplier	
Contact Point for Queries	
Implementation Name(s) and Versions	
Other information necessary for full identification, for example, name(s) and version(s) for machines and/or operating systems; System Name(s)	

A2.1.4 Identification of Specification

CCSDS 431.1-B-1	
Have any exceptions been required? NOTE – A YES answer means that the implementation does not conform to the Recommended Standard. Non-supported mandatory capabilities are to be identified in the PICS, with an explanation of why the implementation is nonconforming.	Yes [ ] No [ ]

A2.1.5 Requirements List

Item	Description	Reference	Status	Values Allowed	Item Supported or Values Supported
VCM-1	Frame type	3.2.1	M	TM, AOS, USLP	
VCM-2	TM and AOS Transfer Frame length	3.2.2.1	C:M	223 to 2048 octets	
VCM-3	USLP Transfer Frame length	3.2.2.2	C:M	223 to 65536 octets	
VCM-4	VCM Type	3.3	1+	1 or 2	
VCM-T1-1	Type 1 VCM mode table used	3.3.1.1	C:1+	table 3-2 or table 3-3	
VCM-T1-2	Type 1 VCM encoder input and output length	3.3.1.2	C:M	as indicated in table 3-2 or table 3-3	
VCM-T1-3	Type 1 VCM encoder output padding	3.3.1.3	C:M	NA	
VCM-T1-4	Type 1, SCCC codes, PLFRAME header length	3.3.1.4.1	C:C:M	320 symbols	
VCM-T1-5	Type 1, TM codes, PLFRAME header length	3.3.1.4.2	C:C:M	256 or 320 symbols	
VCM-T1-6	Type 1, PLFRAME payload length	3.3.1.5	C:M	16 codewords	
VCM-T1-7	Type 1, Pilot insertion	3.3.1.6	C:O	NA	
VCM-T1-8	Type 1, physical layer randomization	3.3.1.7	C:M	NA	
VCM-T1-9	Type 1, baseband shaping	3.3.1.8	C:M		
VCM-T2-1	Type 2 VCM mode table used	3.3.2.1	C:1+	table 3-2 or table 3-4	
VCM-T2-2	Type 2 VCM encoder input and output length	3.3.2.2	C:M	as indicated in table 3-2 or table 3-4	

Item	**Description**	**Reference**	**Status**	**Values Allowed**	**Item Supported or Values Supported**
VCM-T2-3	Type 2 VCM encoder output padding	3.3.2.3	C:M	NA	
VCM-T2-4	Type 2, SCCC codes, PLFRAME header length	3.3.2.4.1	C:C:M	90 symbols	
VCM-T2-5	Type 2, TM codes, PLFRAME header length	3.3.2.4.2	C:C:M	26 or 90 symbols	
VCM-T2-6	Type 2, PLFRAME payload length	3.3.2.5	C:M	1 codeword	
VCM-T2-7	Type 2, Pilot insertion	3.3.2.6	C:O	NA	
VCM-T2-8	Type 2, physical layer scrambling	3.3.2.7	C:M	NA	
VCM-T2-9	Type 2, baseband shaping	3.3.2.8	C:M		
VCM-5	VCM mode table 3-2, modes supported	3.4.2	C:1+	nonempty subset of {1, 2, …, 27}	
VCM-6	VCM mode table 3-3, modes supported	3.4.3	C:1+	nonempty subset of {1, 2, …, 27}	
VCM-7	VCM mode table 3-4, modes supported	3.4.4	C:1+	nonempty subset of {1, 2, …, 28}	

ANNEX B

SECURITY, SANA, AND PATENT CONSIDERATIONS

(INFORMATIVE)

B1 SECURITY CONSIDERATIONS

B1.1 SECURITY BACKGROUND

It is assumed that security is provided by encryption, authentication methods, and access control to be performed at layers above the physical layer and synchronization and coding layer. Mission and service providers are expected to select from recommended security methods, suitable to the specific application profile. Specification of these security methods and other security provisions is outside the scope of this Recommended Standard. The Physical Layer has the objective of delivering data with the minimum possible amount of residual errors. The associated channel coding as described in references [1], [2], and [4] must be used to insure that residual errors are detected and the frame flagged. There is an extremely low probability of additional undetected errors that may escape this scrutiny. These errors may affect the encryption process in unpredictable ways, possibly affecting the decryption stage and producing data loss, but will not compromise the security of the data.

B1.2 SECURITY CONCERNS

Security concerns in the areas of data privacy, authentication, access control, availability of resources, and auditing are to be addressed in higher layers and are not related to this Recommended Standard.

B1.3 POTENTIAL THREATS AND ATTACK SCENARIOS

An eavesdropper can receive and decode the codewords, but will not be able to get to the user data if proper encryption is performed at a higher layer. An interferer could affect the performance of the decoder by congesting it with unwanted data, but such data would be rejected by the authentication process. Such interference or jamming must be dealt with at the Physical Layer and through proper spectrum regulatory entities.

B1.4 CONSEQUENCES OF NOT APPLYING SECURITY

There are no specific security measures prescribed for the physical layer and the synchronization and coding layer. Therefore consequences of not applying security are only imputable to the lack of proper security measures in other layers. Residual undetected errors may produce additional data loss when the link carries encrypted data.

B2 SANA CONSIDERATIONS

The recommendations of this document do not require any action from SANA.

B3 PATENT CONSIDERATIONS

Implementers should be aware that the VCM protocol described in this Recommended Standard relates to CCSDS Recommended Standards references [1], [2], [3], and [4], and that patents relating to those Recommended Standards are described in those references. At the time of publication, CCSDS was not aware of any other claimed patent rights applicable to implementing the provisions of this Recommended Standard.

ANNEX C

INFORMATIVE REFERENCES

(INFORMATIVE)

[C1] *Information Technology—Open Systems Interconnection—Basic Reference Model: The Basic Model*. 2nd ed. International Standard, ISO/IEC 7498-1:1994. Geneva: ISO, 1994.

[C2] *TM Space Data Link Protocol*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 132.0-B-2. Washington, D.C.: CCSDS, September 2015.

[C3] *AOS Space Data Link Protocol*. Issue 3. Recommendation for Space Data System Standards (Blue Book), CCSDS 732.0-B-3. Washington, D.C.: CCSDS, September 2015.

[C4] Jon Hamkins. "Performance of Low-Density Parity-Check Coded Modulation." In *Proceedings of the 2010 IEEE Aerospace Conference (6–13 March 2010, Big Sky, Montana)*, 1–14. New York: IEEE, 2010.

[C5] *Unified Space Data Link Protocol*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 732.1-B-1. Washington, D.C.: CCSDS, October 2018.

ANNEX D

ABBREVIATIONS AND ACRONYMS

(INFORMATIVE)

Term	Meaning
ACM	adaptive coded modulation
AOS	Advanced Orbiting Systems
APSK	asymmetric phase-shift keying
ASM	attached synchronization marker
BPSK	binary phase shift keying
CADU	channel access data unit
CSM	code synchronization marker
DVB	Digital Video Broadcasting
DVB-S2	Digital Video Broadcasting Second Generation
FD	frame descriptor
FEC	forward error correction
K_{bch}	number of bits of BCH uncoded block
LDPC	Low-Density Parity-Check
MSB	Most Significant Bit
OSI	Open System Interconnection
PL	Physical Layer
PLFRAME	Physical Layer frame
PSK	phase shift keying
QPSK	quadrature phase shift keying
SCCC	Serially Concatenated Convolutional Codes
SMTF	synchronization-marked transfer frame
TM	telemetry
USLP	Unified Space Data Link Protocol
VCM	variable coded modulation

ANNEX E

INFORMATIVE SUMMARY OF VCM PROTOCOLS IN REFERENCES [2] AND [3]

(INFORMATIVE)

The VCM protocols in references [2] and [3] are similar in many respects, and contain a few differences. The table below summarizes these similarities. Differences are highlighted in bold type.

	131.3-B-2 (DVB-S2) [3], consistent with Type 2 VCM	**131.2-B-2 (SCCC)** [2], consistent with Type 1 VCM
Basic VCM protocol structure	FM, FD, codeblock, optional pilot	FM, FD, codeblock, optional pilot
Input to Protocol	CCSDS Transfer Frames	CCSDS Transfer Frames
Transfer Frame Sync method	CCSDS ASM	CCSDS ASM
Transfer Frame Slicer?	Yes (asynchronous)	Yes (asynchronous)
FM length	**26 bits**	**256 bits**
FD length	7 bits	7 bits
FD structure	5 bits to specify VCM mode; pilot flag; **long/short frame flag**	5 bits to specify VCM mode; pilot flag; **1 reserved bit**
FD protection	(64,7) linear code	(64,7) linear code
FM + FD TX modulation	$\pi/2$ BPSK	$\pi/2$ BPSK
Pilot symbols	**36 pilot symbols, every 1440 symbols**	**16 pilot symbols, every 540 symbols**
Codes	**DVB-S2**	**SCCC**
Modulations	QPSK, 8-PSK, 16/32-APSK	QPSK, 8-PSK, 16/32/**64**-APSK