The Consultative Committee for Space Data Systems

Draft Recommendation for
Space Data System Standards

# FLEXIBLE ADVANCED CODING AND MODULATION SCHEME FOR HIGH RATE TELEMETRY APPLICATIONS

## DRAFT RECOMMENDED STANDARD

## CCSDS 131.2-P-1.1

## PINK SHEETS

August 2021

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# DOCUMENT CONTROL

| Document | Title | Date | Status |
|---|---|---|---|
| CCSDS 131.2-B-1 | Flexible Advanced Coding and Modulation Scheme for High Rate Telemetry Applications, Recommended Standard, Issue 1 | March 2012 | Current issue |
| CCSDS 131.2-P-1.1 | Flexible Advanced Coding and Modulation Scheme for High Rate Telemetry Applications, Draft Recommended Standard, Issue 1.1 | August 2021 | Current draft:<br>– adds support for the Unified Space Data Link Protocol |

NOTE – Only pages containing substantive changes from the current issue are included in this set of Pink Sheets.

# PREFACE

This document is a draft CCSDS Recommended Standard. Its 'Pink Sheet' status indicates that the CCSDS believes the document to be technically mature and has released it for formal review by appropriate technical organizations. As such, its technical contents are not stable, and several iterations of it may occur in response to comments received during the review process.

Implementers are cautioned **not** to fabricate any final equipment in accordance with this document's technical content.

Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

# 1 INTRODUCTION

## 1.1 PURPOSE

The purpose of this Recommended Standard is to define an efficient and comprehensive coding and modulation solution able to support a wide range of spectral efficiency values and data rates. The main target is given by high data rate telemetry applications (as suggested by the title of this Recommended Standard), i.e., Earth Exploration Satellite Service (EESS) telemetry payload, where the increase of the system throughput by means of advanced adaptive techniques is deemed essential in order to fulfil the requirements imposed by future missions. However, this Recommended Standard may be also adopted for other high-data-rate applications (either space-to-ground, ground-to-space, or space-to-space) and services (e.g., the Space Research service), as long as compliance to CCSDS recommendations for Radio Frequency modulations in reference [4] is ensured.

## 1.2 SCOPE

The current specification presents a turbo-like coding/modulation scheme based on one possible realization of a Serial Concatenated Convolutional Code (SCCC). This scheme makes use of a set of a large variety of modulation techniques (including QPSK, 8PSK, 16APSK, 32APSK, and 64APSK—see reference [4]) and a wide range of coding rates. The number of different modulation schemes available, combined with a properly selected coding rate, allows the overall system to make efficient use of the available bandwidth, adapting itself to the variable conditions of the link. The proposed scheme can implement Variable Coding and Modulation (VCM) mode, which varies the transmission scheme to the channel conditions following a predetermined schedule (for example, as a function of the elevation angle). When a channel[1] is available to provide feedback (e.g., via Telecommand), the transmission scheme can be dynamically adjusted using the Adaptive Coding and Modulation (ACM) mode. The proposed coding scheme is easily adapted to any of the available modulation formats thanks to the pragmatic approach adopted: the outputs of the binary encoders are mapped to the considered modulation scheme, after being interleaved. In other words, a bit-interleaved coded modulation scheme is proposed (reference [F1]).

The use of SCCC is intended mainly for high data rate applications. The Forward Error Correction (FEC) scheme is based on the concatenation of two simple four-state encoder structures. The SCCC scheme implies a Physical Layer frame of constant length, with pilots inserted in fixed positions. This architecture simplifies the synchronization procedure, thus further allowing fast and efficient acquisition at very high rates for the receiver.

This document describes a technique incorporating multiple modulation formats paired with a flexible coding and synchronization method in a tightly integrated fashion. In particular, the document provides a series of recommended formats where each format pairs a modulation technique with a tailored implementation of the coding and synchronization

[1] Such a channel is often referenced as a 'return channel'; however, in CCSDS the 'return link' is associated with space-to-ground transmission of telemetry data.

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.

## 1.7 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 Synchronization and Channel Coding*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 131.0-B-2. Washington, D.C.: CCSDS, August 2011.

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

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

[4] *Radio Frequency and Modulation Systems—Part 1: Earth Stations and Spacecraft*. Issue 23. Recommendation for Space Data System Standards (Blue Book), CCSDS 401.0-B-23. Washington, D.C.: CCSDS, December 2013.

[5] *Unified Space Data Link Protocol*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 732.1-B-2. Washington, D.C.: CCSDS, forthcoming.

NOTE – Informative references are listed in annex F.

# 2 OVERVIEW

## 2.1 ARCHITECTURE

Figure 2-1 illustrates the relationship of this Recommended Standard to the Open Systems Interconnection reference model (reference [F2]). Two sublayers of the Data Link Layer are defined for CCSDS space link protocols. The TM and AOS Space Data Link Protocols specified in references [2] and [3], respectively, and the Unified Space Data Link Protocol (USLP) specified in reference [5], 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 the functions of both the Synchronization and Channel Coding Sublayer and the Physical Layer, the latter as relates to modulation schemes. CCSDS 401.0-B (reference [4]) covers additional features of the Physical Layer, such as frequency bands, polarizations, etc., that are not described or referenced here.

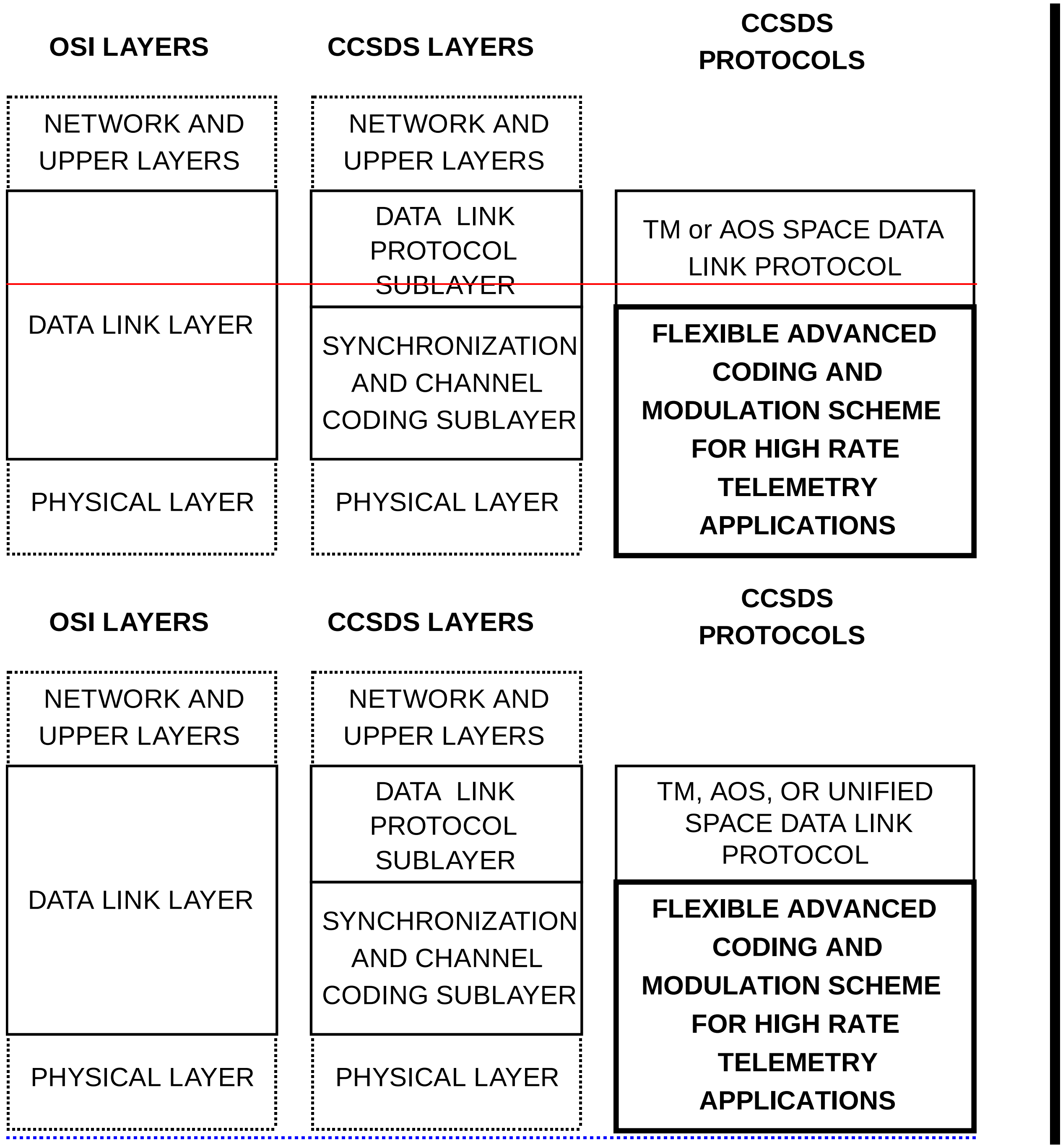


**Figure 2-1: Relationship with OSI Layers**

## 2.2 SUMMARY OF FUNCTIONS

### 2.2.1 GENERAL

This Recommended Standard provides the following functions for transferring Transfer Frames via a stream of bits over a space link:

a) error-control coding (based on serially concatenated convolutional coding), including frame validation;

b) Transfer Frame synchronization and pseudo-randomization; and

c) Physical Layer framing, bit synchronization, and pseudo-randomization.

### 2.2.2 ERROR-CONTROL CODING

This Recommended Standard specifies a turbo-like coding/modulation scheme based on Serial Concatenated Convolutional Code (SCCC) that makes use of a set of a large variety of modulation techniques and a wide range of coding rates.

NOTE – In this Recommended Standard, the characteristics of the codes are specified only to the extent necessary to ensure interoperability and cross-support. The specification does not attempt to quantify the relative coding gain or the merits of each approach discussed, nor does it specify the design requirements for encoders or decoders.

### 2.2.3 FRAME VALIDATION

After decoding is performed, the upper layers at the receiving end also need to know whether or not each decoded Transfer Frame can be used as a valid data unit; i.e., an indication of the quality of the received frame is needed. This function is called Frame Validation.

The SCCC code ensures a very low error probability and there is an extremely low probability of additional undetected errors that may escape this scrutiny. However, these errors may affect the system in unpredictable ways and the Frame Error Control Field is used to enforce the detection of residual errors; i.e., the Frame Error Control Field defined in references [2] ~~and~~, [3], and [5] is used for Frame Validation.

### 2.2.4 SYNCHRONIZATION

This Recommended Standard specifies a method for synchronizing Transfer Frames using an Attached Sync Marker (ASM) (see section 7).

### 2.2.5 PSEUDO-RANDOMIZING

This Recommended Standard specifies a pseudo-randomizer to improve several aspects of the ~~telemetry~~communication link that aid receiver acquisition, bit synchronization, and code synchronization.

## 2.3 INTERNAL ORGANIZATION

### 2.3.1 SENDING END

A general view of the functional blocks of the architecture for the sending end is presented in figure 2-2. This figure identifies functions performed by the system and shows logical relationships among these functions. The figure is not intended to imply any hardware or software configuration in a real system.

At the sending end, the system accepts Transfer Frames of fixed length from the Data Link Protocol Sublayer, performs functions selected for the mission, and transmits a continuous and contiguous stream of physical channel symbols.

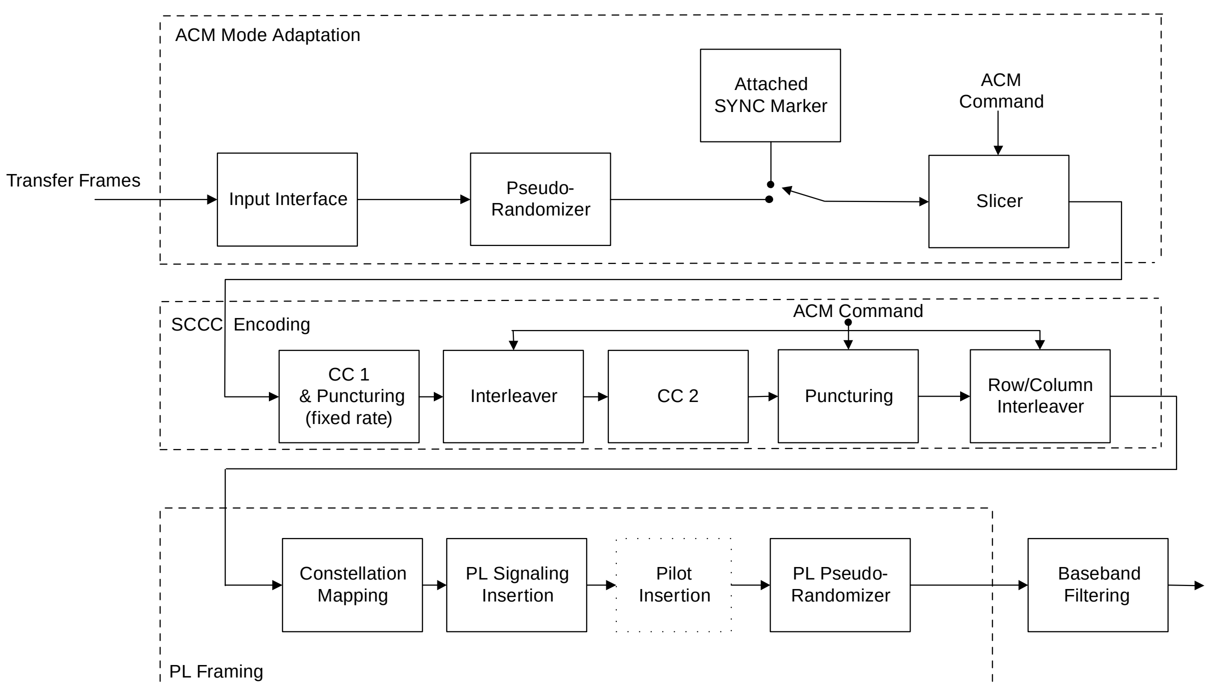


**Figure 2-2: Functional Diagrams at Sending End**

Figure 2-3 illustrates the frame structures and stream formats at different stages of processing. The input stream of Transfer Frames is compliant with the data link protocols in TM (reference [2]) ~~and~~, AOS (reference [3]), and USLP (reference [5]).

# 3 MODE ADAPTATION

## 3.1 OVERVIEW

The mode adaptation unit provides the interface to the incoming stream units. The input interface of the mode adaptation unit maps the input electrical format into a stream of logical bit format.

## 3.2 SCCC SYSTEM INPUT AND INITIAL OPERATIONS

**3.2.1** The SCCC system shall accept TM ~~or~~, AOS, or USLP Transfer Frames from the Data Link Protocol sublayer.

**3.2.2** The SCCC system shall accept only fixed-length USLP Transfer Frames.

NOTE – USLP Transfer Frames can be variable or fixed in length (see reference [5]).

**3.2.3** The Transfer Frame length shall vary between the following minimum and maximum values: 223 octets and ~~2048~~65536 octets (i.e., ~~16384~~524288 bits).

NOTE – The Transfer Frame length is denoted as *M* in figure 2-3. Neither the TM Space Data Link Protocol (reference [2]) nor AOS Space Data Link protocol (reference [3]) specifies the Transfer Frame length. ~~For~~When backward compatibility with legacy data link subsystems is important, the following values are preferable:

a) 1784 bits (=223 × 1 octets);

b) 3568 bits (=223 × 2 octets);

c) 7136 bits (=223 × 4 octets);

d) 8920 bits (=223 × 5 octets).

**3.2.4** The SCCC system shall randomize each frame with the randomizer described in reference [1].

**3.2.5** For each (randomized) Transfer Frame, the SCCC system shall construct a Channel Access Data Unit (CADU) containing the ASM and the Transfer Frame.

NOTE – The CADU is defined in reference [1] as the data unit that consists of the ASM and the Transfer Frame, where the Transfer Frame in the CADU may or may not be randomized.

**3.2.6** The SCCC system shall build a stream of CADUs and provide it to the Slicer.

# 7 FRAME SYNCHRONIZATION

## 7.1 OVERVIEW

### 7.1.1 SYNCHRONIZATION

Frame synchronization is necessary for subsequent processing of the Transfer Frames. Furthermore, it is necessary for synchronization of the pseudo-random generator~~, if used~~ (see section 8).

### 7.1.2 CHANNEL ACCESS DATA UNIT

The data unit that consists of the ASM and the Transfer Frame, consistent with reference [1], is called the Channel Access Data Unit (CADU). The Transfer Frame in the CADU is randomized.

## 7.2 THE ATTACHED SYNC MARKER

**7.2.1.1** Transfer Frames shall be synchronized by using a stream of fixed-length 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 data stream; synchronization is then verified by making further checks.

**7.2.1.2** The ASM shall be SCCC encoded.

## 7.3 ASM BIT PATTERNS

The ASM shall consist of a 32-bit (4-octet) marker with a pattern shown in table 7-1.

**Table 7-1: ASM Bit Patterns**

| | |
|---|---|
| ASM length | 32 bits |
| ASM sequence (Hex) | 1ACFFC1D |

## 7.4 LOCATION OF ASM

**7.4.1** The ASM shall be attached to (i.e., shall immediately precede) the Transfer Frame.

**7.4.2** The ASM shall immediately follow the end of the preceding Transfer Frame; i.e., there shall be no intervening bits (data or fill) preceding the ASM.

# 9 MANAGED PARAMETERS

## 9.1 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 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. However, as mentioned in annex A, the coding and modulation scheme defined in this book also supports parameters that can be changed from one time interval to the next, within a sequence of time intervals in a mission phase. These two types will be referenced in this section respectively as Permanent Managed Parameters and Variable Managed Parameters.

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.

## 9.2 PERMANENT MANAGED PARAMETERS

### 9.2.1 GENERAL

**9.2.1.1** All the managed parameters specified in this section shall be fixed for all Transfer Frames on a Physical Channel during a given Mission Phase.

**9.2.1.2** The Frame Error Control Field defined in reference [2] ~~or~~, [3], or [5] shall be present.

NOTE – The Frame Error Control Field is used for Frame Validation as mentioned in 2.2.3.

### 9.2.2 MANAGED PARAMETERS FOR FRAME SYNCHRONIZATION

The managed parameters for frame synchronization shall be those specified in table 9-1.

**Table 9-1: Managed Parameters for Frame Synchronization**

| Managed Parameter | Allowed Values |
|---|---|
| Transfer Frame Length (octets) | Integer: 223 to ~~2048~~65536 octets |

# 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 Flexible Advanced Coding and Modulation scheme for High Rate Telemetry Applications provides unidirectional (one way) transfer of a sequence of fixed-length TM ~~or~~, AOS, or USLP Transfer Frames at constant frame rate over a Physical Channel across a space link, with optional error detection/correction.

The value of the constant frame rate can be changed from one time interval to the next, within a sequence of time intervals in a mission phase. There can be multiple time intervals within a mission phase. This annex does not specify the method for synchronizing the data exchange between the service user and the service provider when there is a change of frame rate: the synchronization is considered to be part of system management and is out of the scope of this annex.

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 [2] ~~or~~, an AOS Transfer Frame defined in reference [3], or a fixed-length USLP Transfer Frame defined in reference [5].

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

### A3.2 QUALITY INDICATOR

The Quality Indicator parameter shall be used to notify the user at the receiving end of the service that there is an uncorrectable error in the received Transfer Frame.

### A3.3 SEQUENCE INDICATOR

The Sequence Indicator parameter shall be used to notify the user at the receiving end of the service that one or more Transfer Frames of the Physical Channel have been lost as the result of a loss of frame synchronization.

## A4 SERVICE PRIMITIVES

### A4.1 GENERAL

**A4.1.1** The service primitives associated with this service are:

a) ChannelAccess.request;

b) ChannelAccess.indication.

**A4.1.2** The ChannelAccess.request primitive shall be passed from the service user at the sending end to the service provider to request that a Frame be transferred through the Physical Channel to the user at the receiving end.

**A4.1.3** The ChannelAccess.indication shall be passed from the service provider to the service user at the receiving end to deliver a Frame.

### A4.2 ChannelAccess.request

#### A4.2.1 Function

The ChannelAccess.request primitive is the service request primitive for this service.

# ANNEX E

# ACRONYMS AND TERMS

# (INFORMATIVE)

| | |
|---|---|
| **ACM** | Adaptive Coding and Modulation |
| **APSK** | Amplitude Phase-Shift Keying |
| **ASM** | Attached SYNC Marker |
| **AOS** | Advanced Orbiting Systems |
| **AWGN** | Additive White Gaussian Noise |
| **BER** | Bit Error Ratio |
| **CCSDS** | Consultative Committee For Space Data Systems |
| **FD** | Frame Descriptor |
| **FER** | Frame Error Ratio |
| **FM** | Frame Marker |
| **PL** | Physical Layer |
| **PSK** | Phase-Shift Keying |
| **TC** | Telecommand |
| **TM** | Telemetry |
| **SANA** | Space Assigned Numbers Authority |
| **SCCC** | Serially Concatenated Convolutional (Turbo) Code |
| **VCM** | Variable Coding and Modulation |
| **USLP** | Unified Space Data Link Protocol |