The Consultative Committee for Space Data Systems

Recommendation for Space Data System Practices

TM CHANNEL CODING PROFILES

RECOMMENDED PRACTICE

CCSDS 131.4-M-1

MAGENTA BOOK

July 2011

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DOCUMENT CONTROL

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CONTENTS

1 INTRODUCTION

1.1 PURPOSE

The purpose of this Recommended Practice is to provide guidance to users in the choice of the coding scheme to be adopted for their space-to-Earth telemetry links. Given the increasing number of codes available and retained by CCSDS for the transmission of telemetry (TM), it is necessary to clearly define their domain of applicability.

1.2 SCOPE

This document presents recommendations regarding the usage of coding schemes described in references [1]-[2] in the various mission profiles that are encountered in space research, space operations, and Earth exploration.

Within this Recommended Practice it is assumed that at the sending end the Synchronization and Channel Coding sublayer

– accepts at a constant rate transfer frames of fixed length from the Data Link protocol sublayer;

– performs the encoding and synchronization functions selected for the mission; and

– delivers a continuous and contiguous stream of channel symbols to the Physical layer.

at the receiving end, the Synchronization and Channel Coding sublayer:

– accepts a continuous and contiguous stream of channel symbols from the Physical layer;

– performs the synchronization and decoding functions selected for the mission;

NOTE – The decoding functions include validation of frames to determine their quality with respect to the possible presence of undetected errors.

– delivers transfer frames to the Data Link protocol sublayer.

Profiles for Earth-to-space and Proximity links are out of scope and are not addressed in this document. Communication profiles for space-to-Earth links that are currently not supported by CCSDS, e.g., via data relay satellites, are not addressed in this document.

1.3 RATIONALE

Over the years, CCSDS has standardized a set of schemes for forward error correction coding based on state-of-the-art techniques. Indeed, since the needs of missions can be very different, a single type of code would not satisfy all the needs, and possible selections should be offered to the users.

For instance, deep space missions generally operate at low data rates and have, in general, rather mild bandwidth constraints; on the other hand, link performances are crucial and high coding gain is required.

Conversely, near-Earth missions, be they for space research, for space operations, or for Earth exploration, may operate at high or very high data rates on their telemetry link and require, in general, a compromise between coding gain and bandwidth expansion. Punctured convolutional codes were developed specifically for these profiles. Recently introduced LDPC codes appear as a possible alternative with better performances.

Some mission profiles involve highly dynamic links. One of the cases is represented by Earth exploration satellites operating on low Earth orbits. The increasing amount of data to dump to Earth during the short contacts with ground stations requires ever increasing data throughput; techniques based on Variable Coding and Modulation (VCM) are a means to account for the dynamics of the link geometry while keeping constant transmit power. Other causes of variations in the link conditions are the effects of atmosphere at high frequencies. There again techniques like VCM or Adaptive Coding and Modulation (ACM) are useful.

Other missions profiles, such as deep space inter-planetary missions, involve dynamic links as well, but with a slower pace of change. Such missions, operating in the 32 GHz band, may benefit from other forms of link adaptation.

In the process of designing a space communication system, the frequency band, among those made available by the ITU Radio Regulations, is chosen based on the mission characteristics. The frequency band, with its effect on the system design and expected performance, is one of the parameters driving the choice of the coding scheme: it defines the bandwidth availability, the channel physical environment (atmospheric losses, erasures, noise, etc.). Communication and coding profiles for each mission profile are suggested in this Recommended Practice according to the selected frequency bands.

Detailed technical analysis of the codes and modulations is outside the scope of this Recommended Practice and can be found in references [B1] and [B2].

1.4 REFERENCES

The following documents contain provisions which, through reference in this text, constitute provisions of this Recommended Practice. At the time of publication, the editions indicated were valid. All documents are subject to revision, and users of this Recommended Practice 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 Documents.

[1] *TM Synchronization and Channel Coding*. Recommendation for Space Data System Standards, CCSDS 131.0-B-2. Blue Book. Issue 2. Washington, D.C.: CCSDS, August 2011.

[2] *Radio Frequency and Modulation Systems—Part 1: Earth Stations and Spacecraft*. Recommendation for Space Data System Standards, CCSDS 401.0-B-21. Blue Book. Issue 21. Washington, D.C.: CCSDS, July 2011.

NOTE – Informative references are provided in annex B.

2 OVERVIEW

2.1 GENERAL

This section provides an overview of the various types of missions profiles that can be encountered and for which this document provides, in section 3, guidance on the usage of codes on the telemetry links.

At the moment, three categories of mission profiles can be identified:

– Space Research, Near Earth;

– Space Research, Deep Space;

– Earth Exploration.

Each of these mission profiles may include one or several telemetry communication profiles.

2.2 SPACE RESEARCH NEAR EARTH MISSIONS

Orbits of space research near Earth missions range from Low Earth Orbit (LEO), which can be as low as 300 km of altitude, to Medium Earth Orbit (MEO), High Eccentric Orbit (HEO) and up to the Lagrange point L2 at 1.5 million km from the Earth.

Future missions with low or medium data rate needs will operate in the 2200-2290 MHz or 8450-8500 MHz bands. Given the limited available bandwidths per mission in these two bands, 6 MHz (see reference [B3], REC 24-1R1) at 2 GHz and 10 MHz (see reference [B3], REC 5-1R5 and reference [B2], subsection 3.1.2) at 8 GHz, a trade-off between link performance and bandwidth compactness is required, unless the data rates are very low and the link performances critical.

Missions requiring very high telemetry transmission rates are expected to move to the 25.5-27 GHz band, where much larger bandwidths can be assigned per mission. The band presents the drawback of featuring signal attenuations due to the atmospheric conditions; the range of attenuations may be quite high with rather abrupt variations. Traditional Constant Coding and Modulation (CCM) techniques, which do not allow adjusting the link characteristics (data rate, coding rate) to the channel conditions, may prove suboptimum for many mission profiles. Techniques like VCM or ACM are under consideration to mitigate the effects of atmosphere in this frequency band. The 25.5-27 GHz band is a good candidate for missions to the Moon, requiring high rate telemetry either from the Moon surface or from a Moon orbiter to the Earth station.

Therefore two sets of frequency bands are defined for the Space Research, Near Earth mission profile:

a) 2200-2290 MHz and 8450-8500 MHz bands; and

b) 25.5-27 GHz band.

2.3 SPACE RESEARCH DEEP SPACE MISSIONS

Deep space missions are characterized by far distances and thus by critical link performances, whereas the bandwidth occupancy is less of a constraint.

Missions with low telemetry data rates normally operate in the 2290-2300 MHz or the 8400-8450 MHz bands. New missions do not use the 2 GHz band any longer, but it is still occupied for legacy missions. These rather low frequency bands are also preferred for the Launch and Early Operation Phases (LEOPs), when the spacecraft cannot make use of a high gain antenna.

The alternative is the 31.8-32.3 GHz band, used by missions requiring high data rate on their telemetry link to the Earth. The higher frequency allows higher Effective Isotropic Radiated Power (EIRP) for the same antenna size, as compared with the 2 or 8 GHz bands. The 32 GHz band is sensitive to atmospheric conditions but, given the geometry of the deep space links, the effects can, in general, be mitigated with Earth-station diversity.

Therefore two sets of frequency bands are defined for the Space Research, Deep Space mission profile:

a) 2290-2300 MHz and 8400-8450 MHz bands; and

b) 31.8-32.3 GHz band.

2.4 EARTH EXPLORATION MISSIONS

This mission profile addresses Earth exploration missions operating in general in LEO but possibly also in Geostationary Earth Orbit (GEO). Payload telemetry downlinks can be accommodated either in the 8025-8400 MHz band, for moderate to high payload telemetry data rates, or in the 25.5-27 GHz band for future very high data rate payload telemetry. Hence two communication profiles can be identified:

– spacecraft-to-Earth high rate telemetry;

– spacecraft-to-Earth very high rate telemetry.

High rate telemetry ranges typically from a few tens of Mb/s to up to 600 Mb/s whereas very high rate telemetry can go well beyond 2 Gb/s.

The 26 GHz band is to be considered for very high rate telemetry. Links from LEO to the Earth in this band experience not only the effects of the atmosphere but also those of a highly variable link geometry. Hence CCM cannot be used and VCM of ACM techniques are to be considered.

Therefore two sets of frequency bands are defined for the Earth Exploration mission profile:

a) 8025-8400 MHz bands; and

b) 25.5-27 GHz band.

3 TM CODING PROFILES

3.1 GENERAL

In this Recommended Practice a set of choices is given for each profile. The final code selection is eventually made according to the assessment of specific requirements. A few of them are mentioned in the following:

– required error rate performance (i.e., bit/frame error rate at decoder output): for telemetry transfer frame lengths specified in reference [1] the minimum acceptable Frame Error Rate (FER) normally ranges between 1E-04 and 1E-06, with lower values required in case compressed data are carried over the link;

– transmitter power available on board;

– available/selected modulation schemes;

– RF bandwidth limitations, as given in, e.g., subsections 3.1.1 and 3.1.2 of reference [2];

– implementation cost and ground support;

– network of ground stations;

– etc.

In the choice the driving factors are the operational performances and the coding gain. The coding gain is maximized in order to minimize the power required by the on-board transmitter to achieve the specified link performances. The coding gain is obtained at the expense of an increase in channel symbol rate and occupied bandwidth.

Depending on the frequency band used and mission category, the radio frequency bandwidth occupied by the telemetry channel can be subject to limitations. Code rate together with the spectral efficiency of the modulation scheme determines the maximum information bit rate that meets the bandwidth occupancy constraint (reference [B2]).

3.2 CODING SCHEME SELECTION

NOTE – In order to guarantee the required link performance within the bandwidth occupancy constraints and with a signal-to-noise ratio at the receiver compatible with common on-board power budget and RF chain performance, the coding schemes are chosen according to the following recommendations.

3.2.1 For space research near-Earth missions operating their telemetry in the frequency bands 2200-2290 MHz or 8450-8500 MHz one of the following coding schemes is recommended:

a) convolutional codes, rates 3/4, 5/6, or 7/8 concatenated with Reed-Solomon (255, 223) (reference [1]);

b) LDPC codes, rates 2/3, 4/5, or 7/8 (reference [1]).

NOTE – The statistics of error bursts at the output from decoding of the inner code affect the choice of the R-S interleaving depth: an interleaving depth of at least 4 is preferred.

3.2.2 For space research deep space missions operating their telemetry in the frequency bands 2290-2300 MHz or 8400-8450 MHz one of the following coding schemes is recommended:

a) Turbo codes, rates 1/2, 1/3, 1/4, or 1/6 (reference [1]);

b) convolution codes, rate 1/2 concatenated with Reed-Solomon (255, 223) (reference [1]);

c) LDPC codes, rates 1/2, 2/3, or 4/5.

NOTES

1 The statistics of error bursts at the output from decoding of the inner code affect the choice of the R-S interleaving depth: an interleaving depth of at least 4 is preferred.

2 Use of Turbo code rates 1/4 and 1/6 is limited to low data rates, i.e. compatible with the allowed bandwidth allocation.

3.2.3 For Earth exploration missions in LEO operating their telemetry in the frequency band 8025-8400 MHz, the following coding scheme is recommended:

4D-8PSK TCM (reference [2]) in association with Reed-Solomon (255, 239) (reference [1]).

NOTE – For Earth exploration satellites the CCSDS is still studying potential codes using ACM/VCM techniques and, until those studies are complete, the current CCSDS standard (4D-TCM 8PSK) remains the recommended solution.

3.2.4 For space research near-Earth missions operating their telemetry in the frequency band 25.5-27.0 GHz, one of the following coding schemes is recommended:

a) convolution codes, rates 3/4, 5/6, or 7/8, concatenated with Reed-Solomon (255, 223) (reference [1]);

b) LDPC codes, rates 2/3, 4/5, or 7/8 (reference [1]).

NOTE – The statistics of error bursts at the output from decoding of the inner code affect the choice of the R-S interleaving depth: an interleaving depth of at least 4 is preferred.

3.2.5 For Earth exploration missions in LEO operating their telemetry in the frequency band 25.5-27.0 GHz, no current CCSDS standard is recommended.

NOTE – For Earth exploration satellites the CCSDS is still studying potential codes and, until those studies are complete, no CCSDS standard is recommended.

3.2.6 For space research deep space missions operating their telemetry in the frequency band 31.8-32.3 GHz one of the following coding schemes is recommended:

a) Turbo codes, rates 1/2, 1/3, 1/4, or 1/6;

b) convolution codes, rate 1/2 concatenated with Reed-Solomon (255, 223) (reference [1]);

c) LDPC codes, rates 1/2, 2/3, or 4/5 (reference [1]).

NOTES

1 The statistics of error bursts at the output from decoding of the inner code affect the choice of the R-S interleaving depth: an interleaving depth of at least 4 is preferred.

2 All the recommendations above are summarized in table 3-1 for easy reference.

Table 3-1: Coding Schemes

Frequency Band (MHz)	Space Research Near Earth	Space Research Deep Space	Earth Exploration
2 200-2 290 8 450-8 500	Conv 3/4 or 5/6 or 7/8 + R-S (255, 223) (reference [1]) or LDPC 2/3, 4/5 or 7/8 (reference [1])		
2 290-2 300 8 400-8 450		Turbo rate 1/2 or 1/3 or 1/4 or 1/6 (reference [1]) or Conv 1/2 + R-S (255, 223) (reference [1]) or LDPC 1/2 or 2/3 or 4/5 (reference [1])	
8025-8400			4D-TCM 8PSK (reference [2]) + RS (255,239) (reference [1]) (note)
25 500-27 000	Conv 3/4 or 5/6 or 7/8 + R-S (255, 223) or LDPC 2/3 or 4/5 or 7/8		(note)
31 800-32 300		Turbo rate 1/2 or 1/3 or 1/4 or 1/6 or Conv 1/2 + R-S (255, 223) or LDPC 1/2, 2/3 or 4/5	

NOTE – For Earth exploration satellites the CCSDS is still studying potential codes using ACM/VCM techniques and, until those studies are complete, the current CCSDS standard (4D-TCM 8PSK) remains the recommended solution.

ANNEX A

SECURITY

(INFORMATIVE)

A1 SECURITY BACKGROUND

It is assumed that security is provided by encryption, authentication methods, and access control to be performed at higher layers (application and/or transport layers). 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 Practice. The coding layer has the objective of delivering data with the minimum possible amount of residual errors. An LDPC, Reed-Solomon, or other code with Cyclic Redundancy Check (CRC) code 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.

A2 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 Practice. The coding layer does not affect the proper functioning of methods used to achieve such protection at higher layers, except for undetected errors, as explained above. The physical integrity of data bits is protected from channel errors by the coding systems specified in this Recommended Standard. In case of congestion or disruption of the link, the coding layer provides methods for frame re-synchronization.

A3 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.

A4 CONSEQUENCES OF NOT APPLYING SECURITY

There are no specific security measures prescribed for the 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.

ANNEX B

INFORMATIVE REFERENCES

(INFORMATIVE)

[B1] *TM Synchronization and Channel Coding—Summary of Concept and Rationale*. Report Concerning Space Data System Standards, CCSDS 130.1-G-1. Green Book. Issue 1. Washington, D.C.: CCSDS, June 2006.

[B2] *Bandwidth-Efficient Modulations: Summary of Definition, Implementation, and Performance*. Report Concerning Space Data System Standards, CCSDS 413.0-G-2. Green Book. Issue 2. Washington, D.C.: CCSDS, October 2009.

[B3] "SFCG Recommendations." Space Frequency Coordination Group. <https://www.sfcgonline.org/Resources/recommendations/default.aspx>.

ANNEX C

GLOSSARY OF TERMS

(INFORMATIVE)

ACM	Adaptive Coding and Modulation
CCM	Constant Coding and Modulation
CRC	Cyclic Redundancy Check
EIRP	Effective Isotropic Radiated Power
FER	Frame Error Rate
GEO	Geostationary Earth Orbit
HEO	High Eccentric Orbit
ITU	International Telecommunication Union
LDPC	Low-Density Parity-Check
LEO	Low Earth Orbit
LEOP	Launch and Early Operation Phase
MEO	Medium Earth Orbit
PSK	Phase Shift Key
TCM	Trellis Coded Modulation
VCM	Variable Coding and Modulation