OVERVIEW AND GENERAL PRINCIPLES OF SOURCE CODING, CHANNEL CODING & MODULATION IN CCSDS AND DVB-S STANDARDS

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ABSTRACT

Two standardization bodies are currently actively working in the field of space links communication protocols : CCSDS and DVB. These two bodies have developed and specified a series of channel coding and modulation techniques which specifically address the specificities and constraints of space links. Nevertheless, CCSDS and DVB standards differ in many instances because they try to answer different system requirements. The aim of this paper is to present an overview of those techniques with performance comparison between CCSDS and DVB as far as channel coding and modulation are concerned.

1. INTRODUCTION

Two standardization bodies are currently actively working in the field of space links communication protocols. The first one is the Consultative Committee for Space Data Systems (CCSDS) which concentrates on space links for Command & Control (C&C) of satellites, man-tended spacecrafts and deep space probes. The second one is the Digital Video Broadcast (DVB) group which aims to establish the framework for the introduction of MPEG-2 based digital television & data delivery services over a variety of links, including space links for which it has developed the now famous DVB-S standard for digital TV broadcast through satellite.

These two bodies have developed and specified a series of channel coding and modulation techniques which specifically address the specificities and constraints of space links. The aim of this paper is to provide an overview of those techniques with performance comparison. As a conclusion, we propose some general considerations regarding the choice of CCSDS or DVB techniques over a specific space link.

2. CCSDS OBJECTIVES & ACHIEVEMENTS

The Consultative Committee for Space Data Systems (CCSDS) [1] was formed in 1982 by the major space agencies of the world to provide a forum for discussion of common problems in the development and operation of space data systems. The standardization work is led by 3 panels, panel 1 being in charge of space communication protocols development.

2.1. CCSDS space link protocols overview [2]

In the frame of panel 1, a wide range of recommendations have been established and approved as ISO international standards, covering all the aspects of a space link from the physical layer (RF & modulation) to the application layer (source coding, file transfer, …).

In the following, we will develop further the characteristics of the CCSDS compression, TM/TC channel coding, RF & modulation recommendations.

2.2. CCSDS source coding recommendations

In the area of data compression, CCSDS has developed a Lossless Data Compression standard [3][4] either to increase the science return or to reduce the requirement for on-board memory, station contact time, and data archival volume. This standard is based on an adaptive Rice algorithm [5] combined with a preprocessor in charge of input samples decorrelation. The Rice algorithm has been selected by CCSDS mainly because it has a very good performance/complexity ratio (see table 1 for comparison with JPEG-LS standard).

CCSDS is currently developing an image lossy compression standard. This standard will be based on 2D wavelet transform followed by a tree based bit-plane encoder providing an embedded and bit accurate compressed bitstream. This new standard will provide a low complexity alternative to ISO/JPEG2000 for those space missions requiring very high rate, real time image compression within tight power and mass budgets.

Images	CCSDS Rice	JPEG-LS
Lena	1.59	1.88
Los angeles	1.53	1.80
Genes	1.86	2.27

Table 1 – Comparative compression ratio on images for CCSDS and JPEG lossless standards

2.3. CCSDS channel coding recommendations

TM channel coding recommendation [6][7] specifies : a convolutional code, a Reed-Solomon block-oriented code, a concatenated coding system consisting of a convolutional inner code, an interleaver and a Reed-Solomon outer code, and finally a set of turbocodes.

The convolutional code is a rate r = ½, constraint length K = 7 code. Several puncturing schemes are standardized to reach higher rates (2/3, 3/4, 5/6, 7/8) which enable designers to trade power efficiency against bandwidth efficiency. The Reed-Solomon (RS) code is a linear block code operating on bytes. Two options are standardized: RS(255,223) with an error correcting capability of 16 bytes per codeblock, RS(255,239) with a correcting capability of 8 bytes. In the concatenated scheme, an interleaver is used between the RS outer code and the convolutional inner code. The interleaving depth (I) can vary from I = 1 to 8, I=8 providing close to ideal interleave performance. The interleaver is a matrix based interleaver. This concatenated scheme is being used on many spacecrafts including the famous VOYAGER.

In 1999, CCSDS standardized a set of turbo codes that achieve near-Shannon-limit error correction performance. Four rates are available : 1/2, 1/3, 1/4, 1/6. Those codes will typically provide the ultimate power efficiency needed for deep space probes at the expense of a poor bandwidth efficiency. These turbo codes are a combination of two 8 states recursive convolutional codes.

The comparative performances of the CCSDS codes, over a Gaussian channel for BPSK modulation, are given in Table 2. The CCSDS turbo codes are baselined on many spacecrafts now under design.

Type	Efficiency (Bit/symb.)	Theory Eb/No BER=10^{-3}	Theory Eb/No BER = 10^{-5}
No coding	1	6.8 dB	9.6 dB
Conv(7,1/2)	0.5	2.6 dB	4.2 dB
RS(255,223)	0.875	5.5 dB	6.2 dB
Conv(7,1/2) + RS(255,223), I=5	0.437	2.3 dB	2.6 dB
Turbo 1/2	0.5	0.85 dB	1.0 dB
Turbo 1/3	0.33	0.25 dB	0.35 dB
Turbo 1/6	0.167	-0.25 dB	-0.15 dB

Table 2 – Comparative performance of CCSDS conv., RS, concatenated code and Turbo codes (from [7])

CCSDS is currently developing a new recommendation for channel coding specifically optimized for near earth, high rate, bandwidth and power constrained missions. Candidates under review are Block Turbo Codes (BTC) and Low Density Parity Check Codes (LDPCC).

2.4. CCSDS Modulation recommendations

CCSDS Panel 1E was requested by SFCG (Space Frequency Coordination Group) to study bandwidth efficient modulations dedicated to Earth Exploration Services (EES), Space Research Communications for Category A links (near Earth under 2 millions kms), and Space Research Communications for Category B (Deep Space links at more than 2 millions kms from Earth). Applications of these modulations are implemented in the following bands: 2.2-2.3 GHz, 8.4-8.5 GHz, 8.025-8.4 GHz and at a later stage, in the 32 GHz or 37/38 GHz bands. Their characteristics (power, bandwith) have been investigated with extensive analysis taking into account the specificity of a space telemetry link, such as low Eb/No or channel non-linearities.

The following modulations are today standardized:

- for category A: GMSK with BTb=0,25, FQPSK-B™, Filtered OQPSK with different filtering options, i.e. Butterworth or Square Root Raised Cosine (SRRC).
- for category B: GMSK with BTb=0.5, Trellis OQPSK
- for EES at 8 GHz: 4-Dimensional 8-PSK Trellis Coded Modulation (TCM).

For category A and B Modulations, the channel efficiency is of one information bit per transmitted channel symbol. The efficiency of modulation proposed for EES is between 2 and 2,75 bits per transmitted symbol. All those modulations are constant or quasi-constant envelope, fully compatible with a non linear channel (classical satellite links); these modulations are compliant with the SFCG spectrum mask Recommendation Rec 17-2R1 which defines the maximum spectral occupation of modulated carriers with bit rate higher than 2 Mbps.

GMSK and filtered OQPSK modulations are currently used in operational situations by professional industry (e.g. mobile communications); FQPSK-B™ (Feher-Patented Filtered QPSK modulation) is not currently used but offers a good spectral efficiency, comparable to GMSK (BTb=0.35). 4D 8-PSK TCM, based on the works of Ungerboeck and Pietrobon in the years 80 and 90, will be used by CNES for the payload telemetry of Demeter satellite dedicated to seismic monitoring, and also on Pleiades Earth Observation satellite.

Comparison are given in table 3. The EES performances are improved with the use of a RS(255,239) outer code and CCSDS interleaving (I=8), from BER=10^{-3} to 10^{-9}, the Eb/No penalty being equal to 0.3 dB.

Type	Efficiency (Bit/symb.)	Theor. Eb/No BER=10^{-3}	Eb/No BER = 10^{-3}	Eb/No BER = 10^{-5}
Cat. A or B	1 (BPSK) to 2 (other)	6.7 dB	7 to 7.5 dB	9.8 to 10.5 dB
EES	2	4.8 dB	5.1 dB	6.8 dB
EES	2.5	6.4 dB	6.7 dB	8 dB

Table 3: Space Research modulations and 8-PSK EES TCM performances

3. DVB OBJECTIVES & ACHIEVEMENTS

The DVB Project has been created in September 1993 with market-led consortium of public and private sector organizations in the television industry. All the Technical Specifications have been produced by the Broadcast Joint

Technical Committee (JTC) of the European Broadcasting Union (EBU) and the European Telecommunications Standards Institute (ETSI) established in 1990 [8].
As far as its aim is to establish the framework for the introduction of MPEG-2 based digital television services, the common layer for all the DVB standards is the MPEG-2 (188 bytes) Transport Stream [9]. This layer is in fact a Link layer in the sense of OSI model and can map to different Physical layers such as broadcasting standards like the popular DVB-S (Satellite) [10], the DVB-DSNG (Digital Satellite News Gathering) [11]. Recently in 2000/2001, the DVB-RCS (Return Channel by Satellite) [12] has offered Interactive Multimedia capabilities with Medium Access Control (MAC) to the satellite part of the DVB standards.

3.1. DVB-S channel coding & modulation

The DVB-S Standard [10] is dedicated to modulation and channel coding system for satellite multi-program television/High Definition Television Services to be used for distribution in Fixed Satellite Service (FSS) and Broadcast Satellite Service (BSS) Bands.
According to the definition, the following processes are applied to the data stream: transport multiplex adaptation and randomization for energy dispersal, outer coding (i.e. Reed Solomon code), convolutional interleaving, inner coding (i.e. punctured convolutional code), baseband shaping for modulation and carrier modulation.
The outer coding, applied to each randomized transport packet, is based on the Reed Solomon RS(204,188,t=8) shortened code, from the original RS(255,239,t=8) code.
The convolutional interleaver is based on the Forney approach [13]. The interleaved frame is composed of mixed error protected packets delimited by inverted or non-inverted MPEG-2 sync bytes, preserving the periodicity of 204 bytes (RS code frames).
The inner coding is based on a rate 1/2 convolutional code with constraint length K=7 and allows a range of punctured rate : 1/2, 2/3, 3/4, 5/6 and 7/8.
Baseband shaping and modulation are based on a Gray-coded QPSK modulation with absolute mapping, i.e. without differential coding. Prior to modulation, the I and Q signals are Square Root Raised Cosine (SRRC) filtered with a roll-off factor (ro) of 0.35.
The performance requirements for the modem connected in the IF loop, are described in terms of required Eb/No for a $BER=2.10^{-4}$ after Viterbi decoder and Quasi Error Free (QEF) after Reed Solomon decoder. Table 4 (© ETSI) summarizes these performances for the different inner code rate indicated above.

Inner code rate	1/2	2/3	3/4	5/6	7/8
Required Eb/No	4.5 dB	5.0 dB	5.5 dB	6.0 dB	6.4 dB

Table 4: DVB-S BER Performances versus Code Rate

In this table, Eb/No refers to the bit-rate before RS coding and include a modem implementation margin of 0.8 dB. The QEF means less than one uncorrected event per hour, corresponding to $BER=10^{-10}$ to 10^{-11}.

3.2. DVB-DSNG channel coding & modulation

Digital television transmissions can be affected by power limitations but spectrum efficiency has to be increased to reduce the cost of the space segment. Therefore, DVB-DSNG offers different trade-off between power and spectrum efficiency with optional extended values as compared with DVB-S ones.
The transport multiplex adaptation, the randomization for energy dispersal and the outer coding are the same as DVB-S. But for inner coding and modulation, the new concept of “pragmatic” Trellis Coded Modulation [14] has been proposed on 8PSK and 16QAM constellations. With the optional roll-off factor reduction up to 0.25, practical spectral efficiency of 1.51 b/s/Hz (for 8PSK 2/3) to 2.01 b/s/Hz (8PSK 8/9) is achieved for Single Carrier Per Channel transponder configuration (SCPC). This figure rise up to 2.64 b/s/Hz (16QAM 7/8) for Multi-Carrier Per Channel (MCPC) configuration in comparison to the maximum 1.24 b/s/Hz obtained with the classical DVB-S QPSK modulation conv. encoded 7/8 (ro=0.35). The power penalty goes from –0.3 dB (8PSK 2/3) to 2.7 dB (16QAM 7/8). All those modulations are not rotationally invariant or more simply not differentially encoded.

Modulation	Efficiency (Bit/Symbol)	Eb/No $BER = 2*10^{-4}$
8PSK	2	5.2 dB
8PSK	2.5	7.2 dB
8PSK	2.67	7.6 dB
16QAM	3	7.1 dB
16QAM	3.5	8.2 dB

Table 5: DVB-DSNG BER and efficiency performance

Such choices offer the capability to transmit up to 67 Mb/s (SCPC) or 4*23 Mb/s (MCPC) in 36 MHz.

3.3. DVB-RCS channel coding & modulation

Since the DVB-RCS standard [12] has been elaborated for interactive services, the use of the classical forward broadcast delivery link with DVB-S channel coding and modulation was natural. But for the bursty return link traffic, new techniques have been mandatory for performances reasons associated with Multi-Frequency Time Division Multiple Access (MF-TDMA) with fixed or (option) dynamic slot assignment. As far as the convolutional interleaver of the DVB-S leads to too long data packets, shorter size coding were to be found. Among different proposals, three have emerged as part of the standard both over QPSK constellations with SRRC shaping (ro=0.35) :

- No inner coding or even no coding.

- Classical outer RS(204,188) concatenated without interleaver with inner (7,1/2) convolutional code with different rates (puncturing) from 1/2, 2/3, 3/4, 5/6 to 7/8.
- Circular Recursive Systematic Convolutional (CRSC) code [15] with variable rate with use of puncturing 1/3, 2/5, 1/2, 2/3, 3/4, 4/5 and 6/7.

The use of Block Turbo Code has been foreseen but their performance was under the turbo decoding of the CRSC ones for short block and low rate.

Different burst format have been selected based preferentially on the Asynchronous Transfer Mode (ATM) cell. Size in bytes are : 12, 16, 53, 55, 57, 106, 108, 110, 212, 214, 216, 752.

It shall be noted that in order to avoid tremendous combinations, preferred solutions have been defined by ETSI-DVB Group.

Type	Code Rate	Burst size (bytes)	Eb/No FER = 10^{-5}
Conv+RS	1/2*57/73	57	4.3 dB
Conv+RS	3/4*57/73	57	5.7 dB
Conv+RS	7/8*57/73	57	7.1 dB
CRSC	2/5	57	2.4 dB
CRSC	1/2	57	3.1 dB
CRSC	2/3	57	3.7 dB
CRSC	6/7	53	5.8 dB
CRSC	6/7	188	5.1 dB

Table 6: DVB-RCS FER performances [15]

4. CONCLUSION

As far as the goal of CCSDS and DVB standard differs, especially for the use of turbo-coding, it is rather delicate to compare them. But the need for a better power and spectrum efficiency is shared by both standards. The performances indicated above give an idea of how the two standards achieve those requirements. It is to be noted that DVB standards are rather used for geostationary (GEO) satellites with fixed users and a quite constant elevation angle, between 60° to 20°. On the contrary, the CCSDS focuses on Deep Space probes at large distance with tremendous speed, or on Low Earth Orbit (LEO) satellites with moving elevation angles from 5° to 90°. The later case suffers important Doppler effect due to spacecraft motion, leading to more delicate receiving conditions.

Two different approach are used for performance criteria. CCSDS defines Bit Error Rate (BER) and Frame Error Rate (FER) after complete code concatenation while ETSI-DVB uses an intermediate BER observed after Viterbi decoding ([10], [11]). This later case is somewhere uncomplete and can lead to non Quasi Error Free (QEF) systems performances after code concatenation for transmissions with non ideal elements.

The waveform shaping for DVB standards follows always SRRC filtering, leading to envelope modulation and requiring a linear or quasi-linear power amplification while CCSDS modulations are compliant with non linear amplifier with a maximum power efficiency (constant envelope modulations). The comparison of performances between the several modulations offered by the two standards is quite delicate due to the high number of possibilities concerning the inner and outer coding and intrinsic modulation capabilities. The results given in the different tables above can give some help to orientate the choice in a specific direction, according to the requirements of the users.

5. REFERENCES

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