Influence of BCH and LDPC Code Parameters on the BER Characteristic of Satellite DVB Channels

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Abstract—**This article presents the results of a study on the noise immunity of DVB channels when higher-order M-ary APSK modulation schemes and concatenated BCH-LDPC codes are used. Dependencies to determine the probability at the decoder output are given taking into consideration the BCH and LDPC code parameters and the error probability in the communication channel. The influence of the BCH packets length, the BCH code rate, the number of maximum iterations and the parameters of LDPC parity-check matrix on the code efficiency is analyzed. Research of the influence of the concatenated LDPC-BCH code parameters on the radio channel noise immunity is conducted and dependencies to determine the required CNR at the input of the satellite receiver are given.**

Keywords-satellite DVB channel; M-ary APSK; concateneted BCH-LDPC codes; BER; CNR; QEF reception

I. Introduction

The design of a digital communication system aims to maximize the transmission bit rate, to minimize the probability of bit error, to minimize the required power, or equivalently, to minimize the required carrier-to-noise ratio, to minimize the required system bandwidth and to minimize the system complexity and cost. Satellite Digital Video Broadcasting (DVB) systems are particularly affected by power limitations, therefore ruggedness against noise and interference should be the main design objective, rather than spectrum efficiency [1, 2]. In order to achieve high power efficiency without excessively penalizing the spectrum efficiency, such a system should use noise resistant types of modulation and effective channel codes.

Recent trends in satellite communications show an increasing demand of higher-order *M*-ary modulation schemes. Higher-order *M*-ary modulation schemes can provide greater spectral efficiency and thus the high data rate required for either digital multimedia applications or other applications such as point-to-point high data rate backbone connectivity and future Earth observation missions requiring downlink data rates exceeding 1 Gbps. In this regard, Amplitude Phase Shift Keying (APSK) represents an attractive modulation scheme for digital transmission over nonlinear satellite channels due to its power and spectral efficiency combined with its inherent robustness against nonlinear distortion. The design optimization analysis and results obtained for 16, 32 and 64 APSK modulation schemes are presented in [3-5].

The 16 APSK and 32 APSK have been proposed in the framework of the DVB-S2 standard [6] and their performance has been widely investigated over the AWGN channel, by considering typical satellite scenarios, also in the presence of HPAs. Although these higher-order *M*-ary APSK modulation schemes have been specifically designed for operating over nonlinear satellite channels, they still show signal envelope fluctuations and are particularly sensitive to the characteristics of the satellite transponders which introduce channel nonlinearities. As shown in [7, 8], the power efficiency of APSK modulation schemes can be improved by using nonlinear compensation techniques in the uplink station.

In DVB-S2 a concatenated error protection of Bose-Chaudhuri-Hocquenghem (BCH) outer code and Low Density Parity Check (LDPC) inner code was chosen [6, 9]. This FEC scheme can be thought of as a replacement of the DVB-S convolutional coding with LDPC coding and Reed-Solomon encoding with a different BCH encoding. In [10-12] some new design techniques for LDPC and BCH codes are represented which allow approaching the Shannon's capacity to within hundredths of a decibel.

In the contemporary DVB systems it is necessary to provide Quasi-Error-Free (QEF) reception while the values of the CNR parameter are relatively low and the encoding and decoding equipment is not very complex. Quasi-Error-Free means that the Bit Error Rate (BER) at the input of the MPEG-2/4 demultiplexer is less than 10^{-10} to 10^{-11}. In the DVB-S2 standard the requirement for QEF reception shall be satisfied when BER before BCH decoder does not exceed 2.10^{-7}.

For the satellite DVB channel the typical values of the Carrier-to-Noise Ratio (CNR) are within 10 to 18 dB and providing the required BER imposes some limitations on the order of the modulation [2, 13]. Higher-order modulations provide greater transmission bit rate, but they require higher CNR to get the same BER at the output of the demodulator. In [8] and [14] it was shown that, depending on the selected code rate and modulation constellation, the DVB-S2 systems can operate at carrier-to-noise ratios from −2.4 dB (using QPSK 1/4) to 16 dB (using 32 APSK 9/10), assuming an AWGN channel and ideal demodulator. At the same time these systems provide up to a 30% capacity gain over DVB-S systems.

The aim of this paper is to study the influence of the parameters of BCH and LDPC codes on the noise immunity of a satellite radio channel when using 16 APSK, 32 APSK and 64 APSK modulation. It is known that, the 16 APSK and 32 APSK modes are mainly targeted at professional applications (digital TV contribution and news gathering), due to the higher requirements in terms of available CNR, but they can also be used for broadcasting. For this purpose they need to adopt advanced predistortion methods in the uplink station [7, 15] to minimize the effect of transponder nonlinearity.

II. ERROR PROBABILITY AFTER BCH DECODER DEPENDING ON THE CODE PARAMETER

BCH codes fall into the group of block codes, where the digital information is transmitted in packets of a K symbols length. Each symbol consists of n bits, and the greatest applicability belongs to the dual BCH codes, where $n = 1$. The BCH codes are generally represented as BCH(N, K, T), where N is the total number of coded symbols in a packet, and T is the number of repairable symbol errors. For the most common codes $N = 2h - 1$, where h can be every number which is greater than or equals to 3, and $hT = N - K$ is the number of error protection symbols, or checksum.

The symbol error probability after BCH decoding P_S is related to the symbol error probability in the communication channel p_s by the following dependency [16]:

$$P_s = \frac{1}{N} \sum_{i=T+1}^{N} i \binom{N}{i} p_s^i (1 - p_s)^{N-i} . \qquad (1)$$

To obtain the symbol error probability in the communication channel when using M-ary APSK ($M = 16$, 32 or 64) the equations given in [17] can be used.

For the quality assessment of the received digital information the bit error probability parameter (respectively BER) is usually employed. As the paper studies binary BCH codes, the bit error probability after the BCH decoder P_b is equal to the symbol error probability P_S. The relation between bit error probability (p_b) and symbol error probability (p_s) in the communication channel is given by:

$$p_b = p_s (\log_2 M)^{-1} . \qquad (2)$$

In the graphic dependencies represented below, instead of the bit error probability we have used its statistical evaluation BER.

The BCH code efficiency becomes greater with the increasing of the packets length, which makes them appropriate for error correction in packets whose length is far greater than the length of the disturbance. This is illustrated by the dependencies in Figure 1, where the code rate $R_{\text{BCH}} = 0.988$, and the packets length changes from 12000 bits to 20000 bits. The results of the study show that the maximum acceptable values of BER at the input of the BCH decoder which are necessary for providing QEF reception, are within the interval of $1.841 \cdot 10^{-5}$ to $8.222 \cdot 10^{-6}$.

The influence of the checksum on the radio channel noise immunity can be assessed by using the dependencies presented in Figure 2. They are relevant for the case when the packets length is constant ($N = 16200$) and the number of information bits changes from $K = 15880$ to $K = 16136$ (the checksum introduced increases from 64 bits to 320 bits). It is evident that with the increase of the checksum, the radio channel noise immunity becomes better, but this is accompanied by a decrease of its effective bandwidth, and therefore a decrease of the bit rate. The results obtained from this study show that in order to provide BER = 10^{-11} at the BCH decoder output (QEF reception) it is necessary that the BER values at the decoder input do not exceed the following values: $8.81 \cdot 10^{-7,}$ for BCH(16200,16136), $1.62 \cdot 10^{-5}$ for BCH(16200,16008) and $4.47 \cdot 10^{-5}$, for BCH(16200,15880).

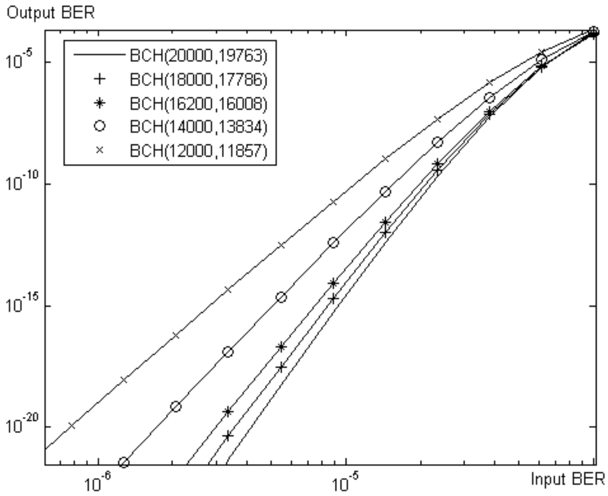

Fig. 1. Output BER versus input BER and BCH packets length

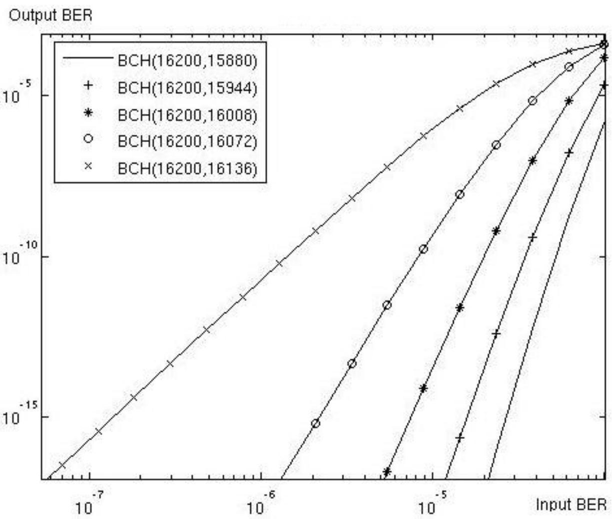

Fig. 2. Influence of the BCH code rate on the output BER

III. ERROR PROBABILITY AFTER LDPC DECODING

LDPC codes are linear block codes which have a sparse parity-check matrix of the type $H_{(N-K) \times N}$, where K is the number of information symbols and N is the total number of coded symbols in the packet. The dual LDPC codes have the widest application. In them every symbol consists of one bit. Unlike most block codes, where the method of maximum likelihood is used for decoding, the decoding algorithm of LDPC codes is based on parallel processing of the parity-check equations with much iteration.

LDPC codes are subdivided into regular and irregular: the latter are more widely used. For them, the dependency between bit error probability after the $(i+1)$-th iteration in the LDPC decoder P_{i+1} and the bit error probability in the communication channel p_b is described by the following expression [18]:

$$P_{i+1} = p_b - \sum_{j=1}^{\omega_c} \lambda_j \left[\begin{array}{l} p_b \sum_{l=\alpha_j}^{j-1} \binom{j-1}{l} Q_i^l (1-Q_i)^{j-1-l} - (1-p_b)\,\mathrm{x} \\ \mathrm{x} \sum_{l=\alpha_j}^{j-1} \binom{j-1}{l} \left(\frac{1-Q_i}{M-1}\right)^l \left(1-\frac{1-Q_i}{M-1}\right)^{j-1-l} \end{array} \right], \quad (3)$$

where

$$Q_i = \frac{1+(M-1)\sum_{q=2}^{\omega_r}\left[\rho_q\left(1-\frac{M\,P_i}{M-1}\right)^{q-1}\right]}{M}. \quad (4)$$

The following symbols are used in these expressions: j and q are the number of the units in a column and a row of the parity-check matrix respectively, λ_j is the relative number of the columns containing j number of units, ω_c is the maximum number of units in a column, ρ_q is the relative number of rows, containing q number of units and ω_r is the maximum number of units in a row. The value of the parameter α_j is chosen as the smallest whole number $\alpha_j > (j-1)/2$, for which the following requirement is fulfilled:

$$\frac{1-p_b}{p_b} \le \frac{Q_i^{\alpha_j}(M-1)^{j-2}}{(1-Q_i)^{2.\alpha_j+1-j}(M-2-Q_i)^{j-1-\alpha_j}}. \quad (5)$$

The LDPC codes in which the number of units in the parity-check matrix rows is the same, and the number of units in its columns is different, have had a wide application in telecommunications. For repeat-accumulate codes, the number of units in the first row is one less than those in the other rows. It is such codes in particular that are used in the DVB standard and that are the research object of this paper.

IV. INFLUENCE OF THE CODE PARAMETERS ON THE BER CHARACTERISTIC OF THE LDPC DECODER

The influence of the maximum number of iterations i_{max} which take place in the LDPC decoder on the code efficiency can be assessed by using the dependencies in Figure 3. For this study we have used the parameters of the original code for the DVB standard. The parity-check matrix of this code is $H_{16200\,x\,64800}$, the number of units in a row is $\omega_r = 14$, the distribution of the number of units in columns is given in Table I and the code rate is $R_{LDPC} = 3/4$.

TABLE I. DISTRIBUTION OF THE NUMBER OF UNITS IN COLUMNS FOR THE LDPC CODES STUDIED.

j	Orig. Code	Code 1	Code 2	Code 3	Code 4	Code 5	Code 6
	Number of columns containing *j* number of units ($\lambda_j \cdot N$)						
1	1	1	1	1	1	1	1
2	4049	4049	4049	4049	4049	4049	4049
3	10800	10300	9800	9300	8100	9450	5400
4	0	0	750	750	0	0	4050
6	0	250	0	250	4050	675	2700
8	0	750	750	1500	0	2025	0
12	1350	850	850	350	0	0	0

As seen in Figure 3, at higher values of the parameter i_{max} the effect of code efficiency increase becomes weaker. Simultaneously, increasing the number of iterations results in longer decoding time, which requires the application of high-speed decoding devices. Therefore, the authors recommend that the maximum number of iterations in the LDPC decoder should not exceed 30.

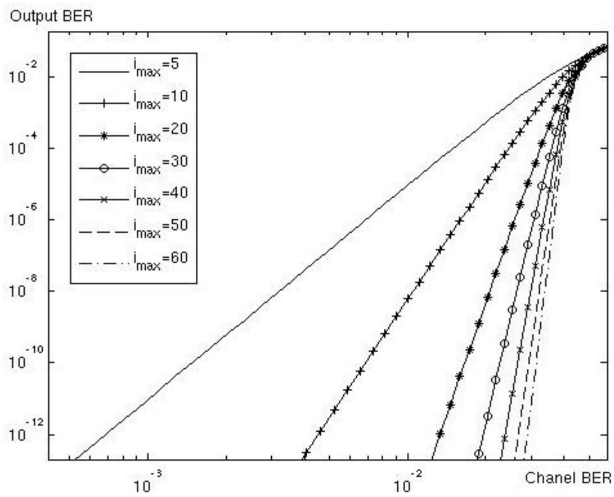

Fig. 3. Influence of the maximum number of iterations in the LDPC decoder on the code efficiency for original LDPC code with code rate = 3/4

Figure 4 shows dependencies of BER after LDPC decoder on BER in the communication channel for a standard and six more irregular LDPC codes. The codes applied have the following parameters: ω_r=14, distribution of the number of units in columns, given in Table I and R_{LDPC}=3/4. For this simulation study it is assumed that the maximum number of iterations in the decoder is i_{max}=20.

From Figure 4 it is evident that when the error probability in the communication channel is greater than $6{\cdot}10^{-2}$, the LDPC code efficiency is very low. The reason for this is the fact that in this case, simultaneously with the errors correction, the decoder also inverts correctly received bits. When the values of the channel BER are lower, the code efficiency increases very rapidly.

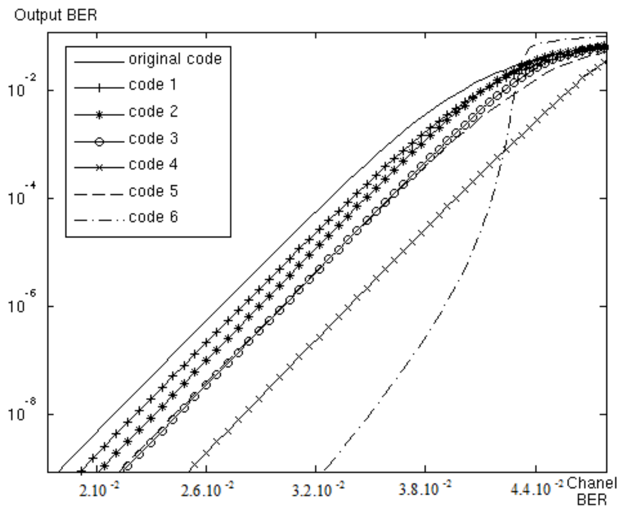

Fig. 4. BER characteristics of the LDPC decoder when $i_{max} = 20$

The results of this study allow obtaining the maximum acceptable values of the BER channel, where a given value of BER at the LDPC decoder output is provided. If, for example, the aim is to obtain an BER=10^{-7} output, then the values of the BER channel are within the interval of $2.31\cdot10^{-2}$ to $3.85\cdot10^{-2}$. It is evident that the highest efficiency is achieved when using Code 4 and Code 6. The efficiency of the LDPC Code 6 become high at lower value of the BER channel compared to other researched codes but its characteristic is considerably steeper. This is due to the lower number of columns containing three ones.

TABLE II. PARAMETERS OF EFFECTIVE LDPC CODES.

	Number of columns containing *j* number of units ($\lambda_j \cdot N$)						
j	1	2	3	4	6	8	12
Code 7 (w_r=12)	1	4049	8100	4050	0	0	0
Code 8 (w_r=15)	1	4049	7650	0	3150	1350	0

Analogous studies have also been conducted for clarifying the influence of the maximum number of units in row ω_r on the LDPC code efficiency. The results show that for achieving maximum efficiency, it is necessary to carry out a careful selection of the ω_r and λ_j parameters of the codes used. The parameters of two LDPC codes which have shown the best results are given in Table II.

V. RADIO CHANNEL NOISE IMMUNITY DEPENDING ON THE CONCATENATED BCH-LDPC CODE PARAMETERS

Considering the selection of a method for channel encoding, it is necessary to take into account the real achievable values of CNR at the input of the satellite DVB receiver. They depend on the equivalent isotropic radiated power (*EIRP*) of the satellite transponder, the signal attenuation along the line satellite-Earth *L*, the gain of the receiving antenna G_A, the noise figure of the low noise convertor NF_{LNC} and the equivalent noise bandwidth of the receiver B_n (the bandwidth is approximately equal to the channel bandwidth B_{ch}). To derive *CNR* we use the following formula [13]:

$$CNR = EIRP - L + G_A - 10\lg B_{ch} - NF_{LNC} + 144\,. \qquad (6)$$

Taking into account the values of the abovementioned parameters, that is *EIRP*=45-65 dBW, *L*=205-211 dB, NF_{LNC}=0.1-0.7 dB and G_A=36–38 dB, it is easy to determine that CNR at the satellite receiver input varies within the limits of 9 to 18 dB. These values cannot be provided when using only one of the codes studied.

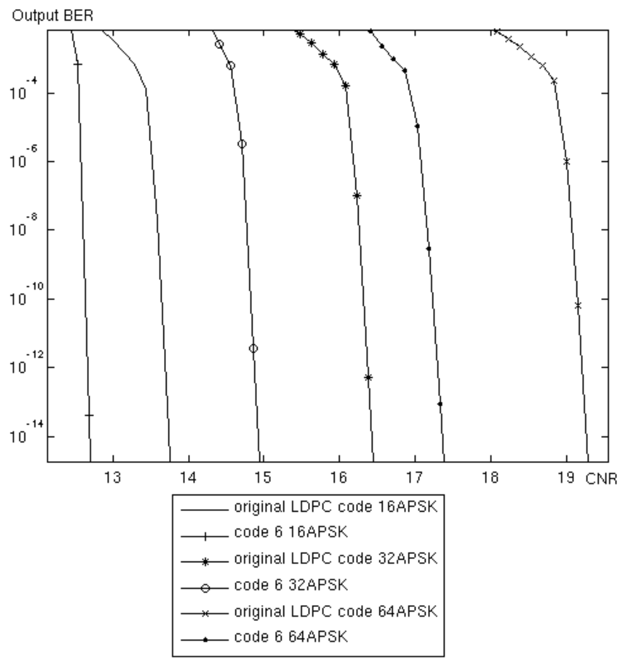

Fig. 5. Influence of the modulation type and BCH-LDPC code parameters on the radio channel noise immunity

The dependencies shown in Figure 5 make possible the derivation of the required carrier to noise ratio, which ensures BER=10^{-11} at the input of the MPEG-2/4 demultiplexer, when concatenated LDPC-BCH codes and M-APSK modulations (M = 16, 32 and 64) are used. During this simulation study it is taken that the LDPC code rate is 3/4, the BCH code is BCH(11880,11712), the maximum number of iterations in the LDPC decoder are i_{max}=20 and the values of ω_r and $\lambda_j N$ are given in Table I and Table II. The relationship between parameters CNR and E_b/N_0 is described as

$$CNR = E_b/N_0 + 10\lg m - 10\lg(1-\alpha/4) - 10\lg(R_{BCH} R_{LDPC})\,, \quad (7)$$

where $m = \log_2 M$ is the number of bits per symbol, α is the roll-off factor of the root cosine square matched filter (α = 0.35, 0.25 and 0.20), R_{BCH} and R_{LDPC} are the code rates of the BCH and LDPC code respectively. The dependencies in Figure 5 refer to the case where α = 0.35.

The analysis of the derived results shows that when concatenated LDPC Code 6 and original BCH code are used the radio channel noise immunity becomes higher than that which is provided in the case of standard concatenated codes. The calculated values of CNR needed for QEF reception and benefits from usage of a modified code, when M-APSK modulations ($M = 16$, 32 and 64) are used, are given in Table III.

TABLE III. CNR VALUES FOR STANDARD AND OPTIMIZED BCH-LDPC CODE OBTAINED BY MEANS OF COMPUTER SIMULATION

Modulation	Standard BCH-LDPC code	Optimized BCH-LDPC code	Benefit
16 APSK	13.67 dB	12.65 dB	1.02 dB
32 APSK	16.35 dB	14.85 dB	1.5 dB
64 APSK	19.17 dB	17.25 dB	1.92 dB

By application of concatenated BCH-LDPC encoding BCH and LDPC code rates can be increased and thus widen the effective channel bandwidth $B_{ch,e}$. As a result, the digital information transmission rate R_b increases. To calculate the value of R_b the following equation can be used:

$$R_b = \varepsilon B_{ch,e} = \varepsilon B_{ch}\left(\frac{1}{1+\alpha}\right) R_{\mathrm{LDPC}} R_{\mathrm{BCH}}, \tag{8}$$

where $\varepsilon = \log_2 M$ denotes the bandwidth efficiency of the selected modulation method.

As known, increasing the manipulation order M and the code rate results in deterioration of the radio channel noise immunity. Therefore, when satellite DVB systems are designed, a reasonable compromise between transmission rate and noise immunity should be done. The calculated values of R_b for the considered concatenated BCH-LDPC codes are within the interval of 20 Mbps (for channel bandwidth $B_{ch} = 27$ MHz, 16 APSK modulation and $R_{\mathrm{LDPC}}=1/4$) to 155 Mbps (for $B_{ch}=36$ MHz, 64 APSK modulation and $R_{\mathrm{LDPC}}=9/10$).

VI. CONCLUSION

The analytic and graphic dependencies presented in this paper make it possible for the optimal parameters of BCH and LDPC codes to be determined taking into account the modulation method, signal attenuation and noise in the radio channel, the receiver parameters, the required BER at the channel decoder output, the transmission rate etc. These dependencies can be used in any other communication system in which such types of encoding are applied.

The analysis of the obtained BER characteristics of satellite DVB channels, for whose formation 16, 32 and 64 APSK and concatenated BCH-LDPC codes with different parameters are used, allows the following conclusion to be drawn. The highest noise immunity of the radio channel is achieved when using a combination of original BCH code and LDPC Code 6. In comparison with the standard concatenated BCH-LDPC code the proposed one provides the following benefits regarding the CNR parameter: 1.02 dB (16 APSK), 1.5 dB (32 APSK) and 1.92 dB (64 APSK).

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