End-To-End Communication Model based on DVB-S2's Low-Density Parity-Check Coding

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***Abstract*—The low-density parity-check codes are one of the most promising coding schemes that allow high throughput, high data rate and good error correction like in the DVB-S2 standard that was the first standard in satellite communication using this coding. The paper presents the concept and bases of low-density parity-check codes and the design strategies used. A simulation model of the end-to-end communication based on low-density parity-check coding is described. The model was designed by using the National instruments' LabVIEW. Simulation results gained with this model show that our model is corresponding to the DVB-S2 standard.**

Keywords-DVB-S2, Digital Television, Low-Densitiy Parity-Check Codes, SPA algorithm, Simulation, LabVIEW

I. INTRODUCTION

Low-density parity-check codes (LDPC) are error correction codes and a class of linear block codes that have a very high throughput and very good coding performance [1].

Originally, the low-density parity-check codes were proposed by Robert Gallager in his thesis in 1962 [2], but this work received no attention because of the encoding and decoding complexity at that time. They were "rediscovered" with the appearance of turbo codes in the 90's by MacKay [3]. Recently, LDPC codes are able to compete in performance with turbo codes and they show the advantage of allowing a finer adjustment of trade-off between performance and decoding complexity [4, 5]. They are suitable for any digital environment where high data rate and good error correction is important [6]. Furthermore, they are suitable for implementations that use advantage of parallelism and take effort of the fact that LDPC codes for large block length perform near the Shannon limit of a channel [7, 8, 9]. The DVB-S2 standard is the first standard using low density parity check codes as its forward error correction.

A wide array of other communication application uses LDPC codes such as the 10 Gigabit Ethernet, the broadband wireless access or the deep-space communication [10, 11]. Adoption of LDPC codes is one of the keys to achieve lower transmission power and more reliable communication [11]. In this article, we detail a simulation model of a low-density parity-check channel coding system developed via use of National Instruments' LabVIEW [12].

The low-density parity-check codes and their basic concept are discussed in Section II. Section III describes the LDPC based end-to-end communication model. The performance and results are shown in Section IV. Section V concludes the article.

II. THEORETICAL BACKGROUND

Low-density parity-check codes are binary linear codes where a block of data is encoded into a codeword. They are obtained from sparse bipartite graphs [13], the so called Tanner graph [14] which consists of two types of nodes: of n variable or message nodes and of r check nodes [15]. Out of these graphs can be derived a linear code of block length n and dimension of at least $n–r$. Such a graph representation has an analogue matrix representation. The LDPC codes are specified with their sparse parity-check matrix **H** of the size $M \times N$. Two numbers define such a matrix: ω_r is the number of ones in every row and ω_c is the number of ones in every column. If $\omega_c << N$ and $\omega_r << M$ then such a matrix is called a low-density (sparse) and is usually very large.

When the check node j from the Tanner graph is connected to the variable node i the entry (i, j) of **H** is 1 with $j \in \{0, ..., N\text{-}1\}$ and $i \in \{0, ..., M\text{-}1\}$. That means that the corresponding codeword bit takes part in the corresponding parity-check equation [5]. When there is no connection then **H** (i, j) = 0 [15].

A) Decoding

The decoding algorithm named the sum-product algorithm (SPA) was already proposed by Gallager in 1962 [2, 3]. There are two types of this algorithm: the hard and the soft decision. The hard decision decoding is mainly introduced for educational purpose but since the soft decision decoding provides better decoding results [1] it will be focused on. Soft-decision decoding of LDPC codes is based on concept of belief propagation. It is an iterative process where the information of the received bits is refined iteration by iteration [16]. First, variable node c_j sends its message q_{ij} to the f_j-check node. q_{ij} contains the amount of belief the message bit y_i is a zero and the amount of the belief, Pi that y_i is a one:

$$\begin{aligned} q_{ij}(1) &= P_i \\ q_{ij}(0) &= 1-P_i \end{aligned} . \qquad (1)$$

Based on (1), the check nodes calculate the probability of c_i to be zero which is the same as calculating an even number of ones among all other variable node but except variable node c_i:

$$\begin{aligned} r_{ij}(0) &= \frac{1}{2}+\frac{1}{2}\prod_{i'\in Vj/i}(1-2q_{ij}(0)) \\ r_{ij}(1) &= 1-r_{ij}(0) \end{aligned} . \qquad (2)$$

Information calculated in (2) is sent back to the variable nodes to update:

$$\begin{aligned} q_{ij}(0) &= K_{ij}(1-P_i)\prod_{j'\in Ci/j} r_{i'j}(0) \\ q_{ij}(1) &= K_{ij}P_i\prod_{j'\in Ci/j} r_{i'j}(1) \end{aligned} , \qquad (3)$$

$$q_{ij}(0)+q_{ij}(1)=1 \ , \qquad (4)$$

where K_{ij} is a constant chosen so that equation (4) is satisfied and C_i/j represents all check nodes but not f_j.
The variable nodes recalculate their estimation:

$$\begin{aligned} Q_i(0) &= K_i(1-P_i)\prod_{j\in Ci} r_{ji}(0) \\ Q_i(1) &= K_iP_i\prod_{j\in Ci} r_{ji}(1) \end{aligned} , \qquad (5)$$

vote for the bigger one and repeat the recalculation until the probability of ones (or zeros) is high enough [1, 17].

B) Encoding

The decoding algorithm does only the error correction. For protecting the message from noise and intersymbol interference the message has to be encoded. Encoding of message is done using the parity-check matrix **H**:

$$\mathbf{H}=\begin{bmatrix} H_1 & H_2 \end{bmatrix} \quad , \qquad (6)$$

$$\mathbf{H}_2=\begin{bmatrix} 1 & & & & & 0 \\ 1 & 1 & & & & \\ & 1 & 1 & & & \\ & & \cdot & \cdot & \cdot & \\ 0 & & & & 1 & 1 \end{bmatrix} \qquad (7)$$

where $\mathbf{H_1}$ and $\mathbf{H_2}$ are matrixes of size $(N-K)\times K$ and $(N-K)\times(N-K)$. N is the block length and K is the number of message bits. Thus defined, $(N-K)$ are the parity bits. $\mathbf{H_1}$ is a sparse matrix and $\mathbf{H_2}$ is defined with following equation (7). Since the low-density parity-check codes are mostly extended irregular repeat-accumulate codes (eIRA), [18] the encoding can be done via the parity-check matrix with linear complexity by noting:

$$\mathbf{H}c^T=0 \, , \qquad (8)$$

where c is the codeword [17]. Equation (8) has to be solved for parity bits recursively [18].

In many other applications, additional outer coding techniques are used in order to ensure higher communication quality, e.g. the outer Bose-Chaudhuri-Hocquengheim, BCH code [19] in the DVB-S2 system cleans up additional errors and improves the overall performance [7].

Broadcast applications, mainly use code (frame) length of 64800 [7] or 16200 [6] and variable code rates from 1/4 up to 9/10 [16]. Individual parity-check matrixes are defined for each code rate [3]. Coded data blocks that come from the encoder are always of the same length. The number of message information bits is not constant and depends on the code rate [16, 20].

III. MODELING

In this section our simulation model of end-to–end communication based on DVB-S2’s LDPC coding method was presented.

National Instruments’ Laboratory Virtual Instrument Engineering Workbench LabVIEW with its Modulation Toolkit is used to design the end-to-end communication model because LabVIEW virtual instruments (VIs) can be built simple and combined to produce a flexible and powerful communication test system [21]. LabVIEW is based on graphical programming and in contrast to the sequential logic of most text-based programming languages; the execution of a block or graphical component dependents on the flow of data. More specifically, a block executes and the output data are sent to all other connected blocks when all input data are made available.

Figure 1 presents the main block scheme of our communication model. Via the Bit generator, message to be sent is generated and sent to the LDPC code. After coding, message is modulated onto the carrier, filtered with the root raised cosine filter and sent through the AWGN (Gaussian white noise) channel. At the receiver’s side, the received message is filtered, demodulated and decoded. In order to measure the communication quality, the bit error rate is calculated and plotted on the BER versus E_b / N_0 graph. E_b stands for energy per bit and N_0 is the noise power of spectral density [20].

Before simulating the communication system, some optional parameters of the system may be predefined by simply texting them at the Front panel, a LabVIEW provided graphical user interface. The input parameters for the program are the code rate defined with the size of the parity-check matrix (n – number of rows in the matrix, m- number of columns in matrix):

$$R = \frac{n}{m}, \tag{9}$$

as well as the number of ones in one column and the maximal number of iterations performed by the encoder and decoder. The program uses this information to calculate the matrix H for the encoding and decoding process. The code rates, according to the standard are [2]: 1/4, 1/3, 2/5, 1/2, 3/5, 2/3, 3/4, 4/5, 5/6, 8/9 and 9/10.

The DVB-S2 standard specifies two word lengths for the LDPC: 16200 or 64800 bits. Since the longer word length is used for sending information through channel, only the word length of 64800 bits will be considered in this paper. It has to be denoted that the coded message, delivered from the encoder is always the same length, but the number of information bits is not constant and depends on the code rate.

For decoding the received messages different algorithms may be used. In our work the Sum-product algorithm decodes the message. It exchanges the soft-information iteratively between variable and check nodes. Updating the nodes can be done with a canonical, two-phased scheduling: In the first phase all variable nodes are updated and in the second phase all check nodes. The processing of individual nodes within one phase is independent and can thus be parallelized. The exchanged messages are assumed to be log likelihood ratios (LLR). Each variable node calculates an update of message according to equations (1)-(5).

Next input parameter for the program is the modulation parameter M for the M-PSK modulation. According to the standard [2], the PSK modulates the message onto the carrier although other modulation types, like the amplitude modulation may be used, too.

For filtering the root-raised cosine filter is used. The default value of the roll-off factor of this filter is set to $\alpha = 0.35$ but may be changed to values according to [2].

The user also defines the symbol rate for sending the message.

In our version of the model, there was no use for the BCH (Bose-Chaudhuri-Hocquenghem) encoder. BCH is not very good for error protection and correction itself, but it performs the erasure of error floor after the LDPC encoder encoded the message.

IV. RESULTS

As the result, the BER versus E_b / N_0 curve is plotted in order to show the system performance, analyse the communication quality itself and the parameter influence on communication quality. First, the performance of LDPC coding is shown. The coding gain for the no coded and the LDPC coded message is calculated. The influence of the modulation parameter M is shown and the third simulation result is made in order to show how the code rate affects the communication quality.

In Fig. 2, the BER versus E_b / N_0 graph for the LDPC coded and no coded BPSK is shown. Since communication with higher modulation parameter M gained same conclusion as with the BPSK, this modulation type, being the simplest one was chosen to show system performance. Other relevant system parameters for the simulation are given in Table 1. Simulation result shows that, as expected, coding improves the performance of the communication system. Low-density parity-check coding is an error correction code that ensures not only error protection of the message but also error

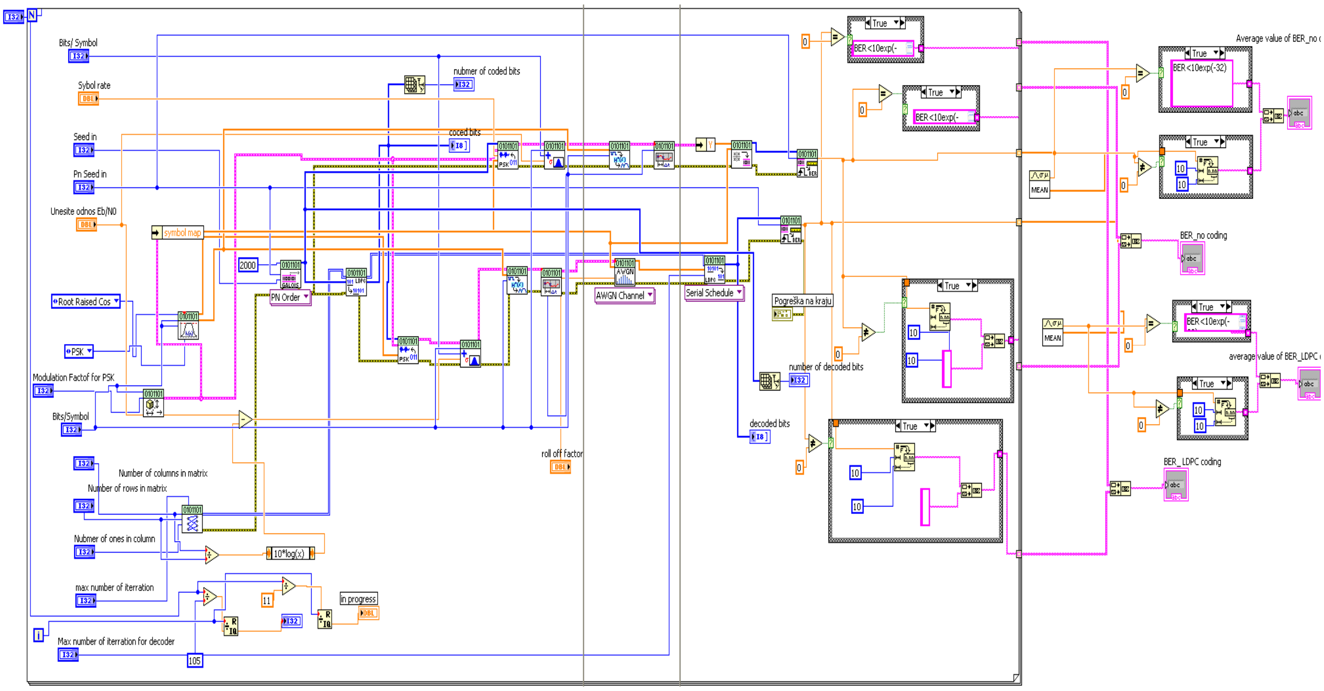

Figure 1. Block diagram of our end-to-end communication model based on DVB-S2’s low-density parity-check coding

TABLE I. SYSTEM PARAMETRS FOR SIMULATION 1

System parameters	Modulation type:	BPSK
	Filter's roll-off factor:	$\alpha = 0.35$
	DVB-S2 frame:	64800 bits
	DVB-S2 pilots:	no
	LDPC code rate:	1/2
	Bits per Symbol:	1
	Symbol rate:	30.00000000 Mbaud
Parity-check matrix parameters	Number of iterration:	100
	Number of rows:	200
	Number of coloums:	400
	Number of 1s in row:	5

correction. This is why the coded BER curve is shifted to the left of the BER curve of the no coded message meaning that the transmission is more accurate and better communication quality is ensured. The coding gain for reaching $BER = 10^{-6}$ is calculated and amounts coding_gain= 7.4 dB.

The influence of parameter M is tested and communication quality is shown in Fig. 3. Therefore, the QPSK, 8-PSK and 16-PSK modulated, LDPC coded and root raised cosine filtered (with the roll off factor $\alpha = 0.35$) message is generated. The code rate $R = 3/4$ is achieved with matrix parameters as follows: number of rows in parity-check matrix was 300 and number of columns was 400. There were 5 ones in every column. The maximal number of iteration for the coder and decoder was set to 100. Other system parameters are given in Table 1.

Simulation results show that the BPSK gained the best communication quality. The BER curves for the QPSK and the 8-PSK are shifted to the right of QPSK's bit error rate versus E_b / N_0 graph showing that by lowering the modulation factor *M*, the communication becomes accurate and safer. For the same noise level in system the probability of error during communication is lower.

TABLE II. CODE RATE DEFINED WITH NUMBER OD ROWS AND COLUMNS OF THE PARITY-CHECK MATRIX

Code rate	1/2	2/3	3/4	5/6	7/8
Number of rows	200	200	300	250	350
Number of columns	400	300	400	300	400

Figure 4 shows the influence of the code rate on the bit error rate. For modulating the signal onto the carrier the phase shift keying modulation was used with its modulation factor set to $M = 2$. Filtering was done with the root raised cosine filter's roll off factor set to $\alpha = 0.35$. The parity-check matrix had 5 ones in every column and its size was changed in order to gain different coding rates according to Table 2. Other parameters were as it is given in Table 1.

Simulation shows that by lowering the code rate, communication becomes much safer. As the code rate reduces, more parity bits are used to protect one single bit. Therefore, a lower code rate ensures better communication quality but provides lower bit rate. With a lower code rate more bits have to be sent for transmitting the same message then with a higher value of the code rate and this takes more time. The lowest bit error rate, with a constant level of noise in system is achieved with code rate set to $R = 1/2$. The code rate is defined by the size of the parity-check matrix.

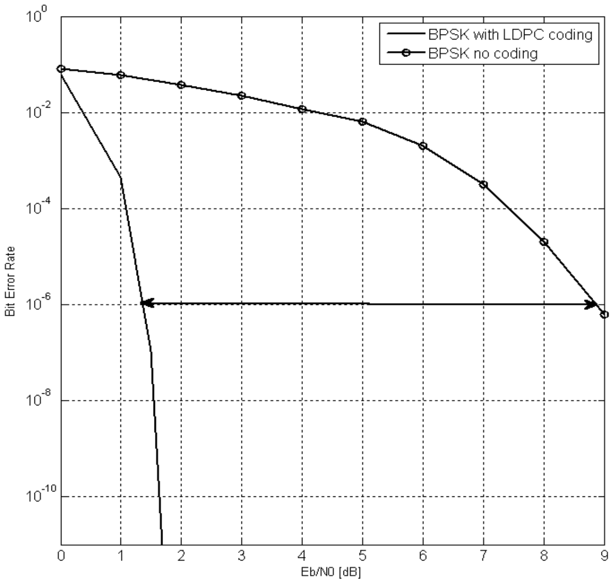

Figure 2. BER versus E_b / N_0 graph for the coded and the no coded message

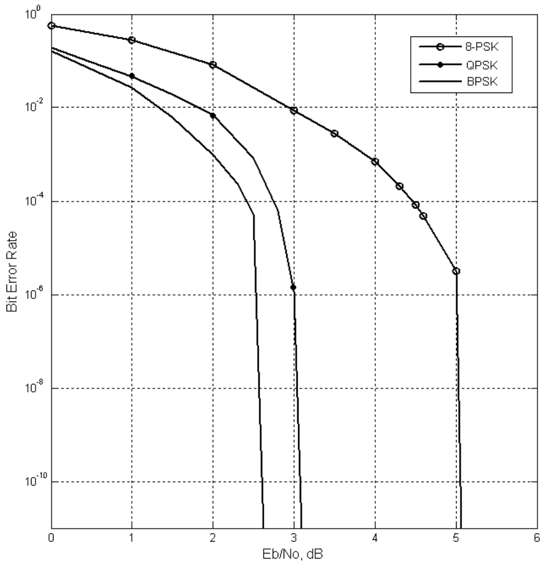

Figure 3. BER versus E_b / N_0 graph for different modulation factors of the phase shift keying modulation message

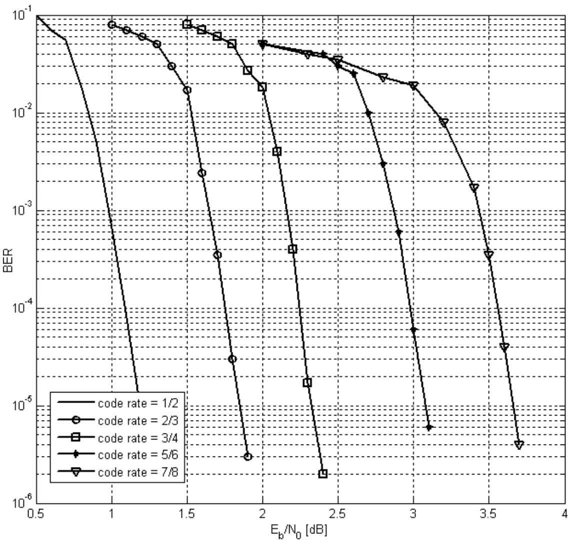

Figure 4. BER versus E_b / N_0 graph for different code rates

The number of rows and columns in the parity-check matrix directly defines the value of bit error rate of the system.

V. CONCLUSION

In this paper, after a basic theoretical background on low-density parity-check codes, our end-to-end simulation model based on DVB-S2's LDPC coding is presented. For modeling the National Instruments' LabVIEW and its Modulation Toolkit were used. Encoding is based on forming the parity-check matrix. At the receiver's side, decoding is done. Decoding of received message is done via the sum-product algorithm and soft decision decoding.

Simulations were made and the influences of different parameters were tested. Results show that low-density parity-check codes improve the communication quality. Lowering the modulation factor *M* gained a lower bit error rate in system, as well as reducing the code rate. Since, with lower code rate more bits have to be sent for transmitting the same message the transmitting takes a higher bit rate.

In future work, the model will be augmented with an outer BCH encoder in order to improve the existing model and move it closer to the DVB-S2 standard.

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