DVB-S2 Model Based on Reed-Solomon Outer Encoder

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***Abstract*—This paper analyzes the performance of a new DVB-S2 system. The standard outer Bose-Chaudhuri-Hoquenghem encoder is substituted with a Reed-Solomon (204, 188) encoder in order to analyze and possibly improve the system performances. Simulation for analyzing the communication quality is designed via Matlab and Simulink. The results are compared with results from the existing DVB-S2 model. The new model with the Reed-Solomon outer encoder shows better performances: when noise reaches a level where the existing model gains no quasi-error free performance, the new DVB-S2 model shows a quasi-error-free communication.**

Keywords-DVB-S2; Reed-Solomon; outer encoder; communication system design.

I. INTRODUCTION

DVB-S2 is the second generation specification for satellite broadcasting and part of the European standard, the EN 302 307 [1]. The new combination of a sophisticated coding scheme based on the low-density parity-check, LDPC inner codes concatenated with the Bose-Chaudhuri-Hoquenghem (BCH) outer codes allows a quasi-error-free operation very near the Shannon limit [2], spectral capacity increase by 30-35% over the DVB-S standard for a given symbol rate and carrier to noise ratio is accomplished with modulation and coding schemes of higher order [3]. The DVB-S2 system was designed for high definition television, interactive applications like Internet navigation etc. providing them the best transmission performance, total flexibility and receiver with reasonable complexity [4].

In an earlier work [5], we designed simple communication models designed for analyzing influence of different model parameters on communication quality. These simulations showed that models perform better when the message is coded with the Reed-Solomon code over the BCH code. Therefore, the idea is to substitute the existing BCH code in the DVB-S2 model with the Reed-Solomon code in order to test the communication quality after substitution. Simulation is made using Matlab/Simulink.

This paper is organized as follows. Section II describes the bases of Reed-Solomon encoder and its implementation in the new DVB-S2 model based on the Reed-Solomon outer encoder. In Section III, the simulation models of both, the standard and the new DVB-S2 systems are given. Simulation results are presented in Section IV and Section V concludes the paper.

II. THEORETICAL BACKGROUND

A simplified model of the DVB-S2 transmitter is given in Figure 1. The model is based on two codes: the outer BCH code and the inner LDPC code. The binary message of length *k'* (generated with the bit generator) is encoded into a BCH codeword of length *n'*. The BCH code is a multilevel cyclic variable-length digital error-correcting code used to correct multiple random error patterns [4].

The BCH codeword is sent to the LDPC outer encoder and treated as a message of length *k=n'* to be encoded into a *n*-bit-long systematic LDPC codeword. The LDPC codes are type of error-correcting codes presented with a large sparse parity-check matrix $\boldsymbol{H}$ of the size $M\times N$. The sparse matrix is defined with the number of ones, $\omega_r << N$ in every row and the number of ones in every columns, $\omega_c << M$ [6], [7]. The parity-check matrix may be written as:

$$H = \begin{bmatrix} H_1 & H_2 \end{bmatrix} \quad (1)$$

$$H_2 = \begin{bmatrix} 1 & & & & 0 \\ 1 & 1 & & & \\ & 1 & 1 & & \\ & & \cdot & \cdot & \cdot \\ 0 & & & 1 & 1 \end{bmatrix} \quad (2)$$

where $\boldsymbol{H_1}$ and $\boldsymbol{H_2}$ 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. So defined, *(N-K)* are the parity bits. $\boldsymbol{H_1}$ is a sparse matrix and $\boldsymbol{H_2}$ is defined with equation (2). Since the low-density parity-check codes are mostly extended irregular repeat-accumulate codes (eIRA) [8], the encoding can be done via the parity-check matrix with linear complexity by noting:

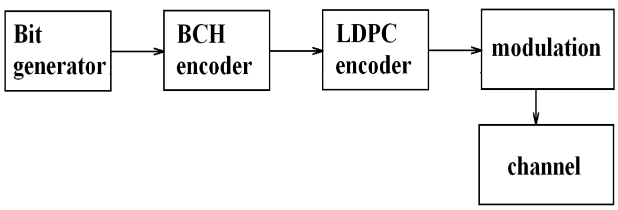

Figure 1. Simplified DVB-S2 transmitter model.

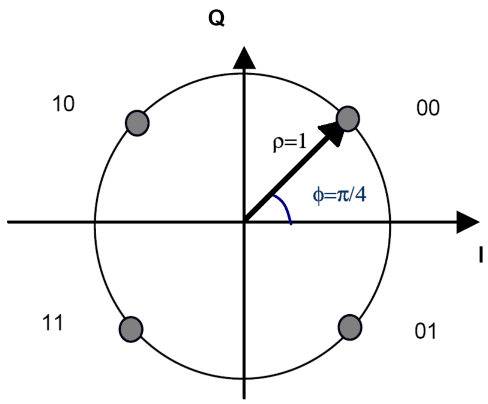

Figure 2. The Gray coded QPSK mapping.

$$Hc^T = 0\,, \tag{3}$$

where *c* is the codeword [9]. This has to be solved for parity bits recursively [10].

According to the DVB-S2 standard [1], the codeword may be of length *n*= 64800 or *n*=16200 referencing the normal and the short frame messages. The ratio *k/n* at the LDPC encoder defines the code rate of system. The DVB-S2 standard defines eleven different code rates for the normal frame messages: 9/10, 8/9, 5/6, 4/5, 3/4, 2/3, 3/5, 1/2, 2/5, 1/3 and 1/4. Short frames are suitable for all the same code rates, except for rate 9/10 [1].

The coded message is modulated onto a carrier via the QPSK, 8PSK, 16APSK or the 32APSK modulation depending on application area. Gray mapping is used for QPSK (Figure 2) and 8PSK modulation schemes [1].

Reed-Solomon codes showed to be suitable when mentioned burst errors occur. This paper presents a new DVB-S2 system where the BCH encoder is substituted with the Reed-Solomon coder (Figure 3).

With the Reed-Solomon code, the bits are grouped into symbols, instead of being encoded directly in bits. The data words and code words are encoded in these symbols.__

The Reed-Solomon code is specified as RS (*n'*, *k'*) and every Reed-Solomon symbol has *s* bits. The code takes *k'* original-message-symbols and encodes it into *n'* symbols. The number of redundant bits is *n'*-*k'* and they are not part of the message itself but are sent through the channel to protect the useful message. The number of possible codewords is *2N*, but only *2K* contain data words. The rest of the codewords are not contributing to the message and are redundant.

If errors occur, there is a high probability that they will convert the permissible code words into one of the redundant words that the decoder at the receiver is designed to recognize as an error [11]. The number of symbol errors that may be corrected, *t* is defined:

$$2t = n' - k'. \tag{5}$$

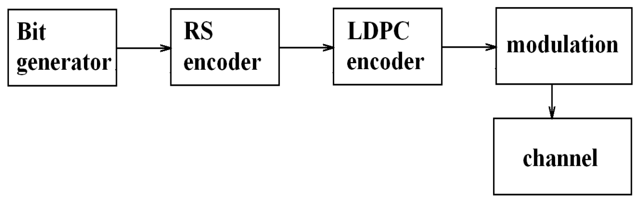

Figure 3. Simplified block scheme of new transmitter model

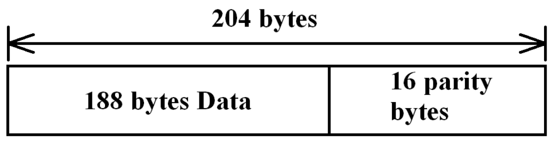

Figure 4. A Reed-Solomon codeword.

The Reed-Solomon code may detect and correct a corrupted symbol with a single bit errors as it can a symbol with all its bits in error, meaning that the Reed-Solomon code is suitable for correcting burst errors [4].

The DVB code is the Reed-Solomon (204, 188) code using 8-bit symbols [12]. The Reed-Solomon (204, 188) is the shortened code, from the original Reed-Solomon (255, 239) code and it will be applied to each randomized transport packet (of 188 bytes) to generate an error protected packet. The Reed-Solomon code adds the parity bytes after the information bytes of the transport packets (Figure 4). In DVB standards, the Reed-Solomon code can correct up to 8 erroneous bytes per packet.

III. SIMULATION MODEL

Our simulation model is based on implemented DVB-S2 simulation in Matlab; command 'commdvbs2' (Figure 5).

Before simulating the existing model, simulation and system parameters will be chosen. The user has to define the code rate as well as the modulation scheme prior starting simulation. The simulation takes the 188 bytes long random binary sequence generated by using the Bernoulli generator (packet sourced) as its input. The message is sent through an AWGN channel and received at the receiver, demodulated and decoded. The bit error rate, BER is calculated after the low-density parity-check code block and the packet error, PER is calculated after the outer Reed-Solomon code block. Additionally, the simulation provides the constellation diagram for particular communication model.

Our DVB-S2 model is presented in Figure 3 and its Matlab realization in Figure 5. The simulation used only the quadrature phase shift keying modulation scheme (Figure 2). The code rates may be set to any code rate supported by the DVB-S2 standard, as listed in Section II.

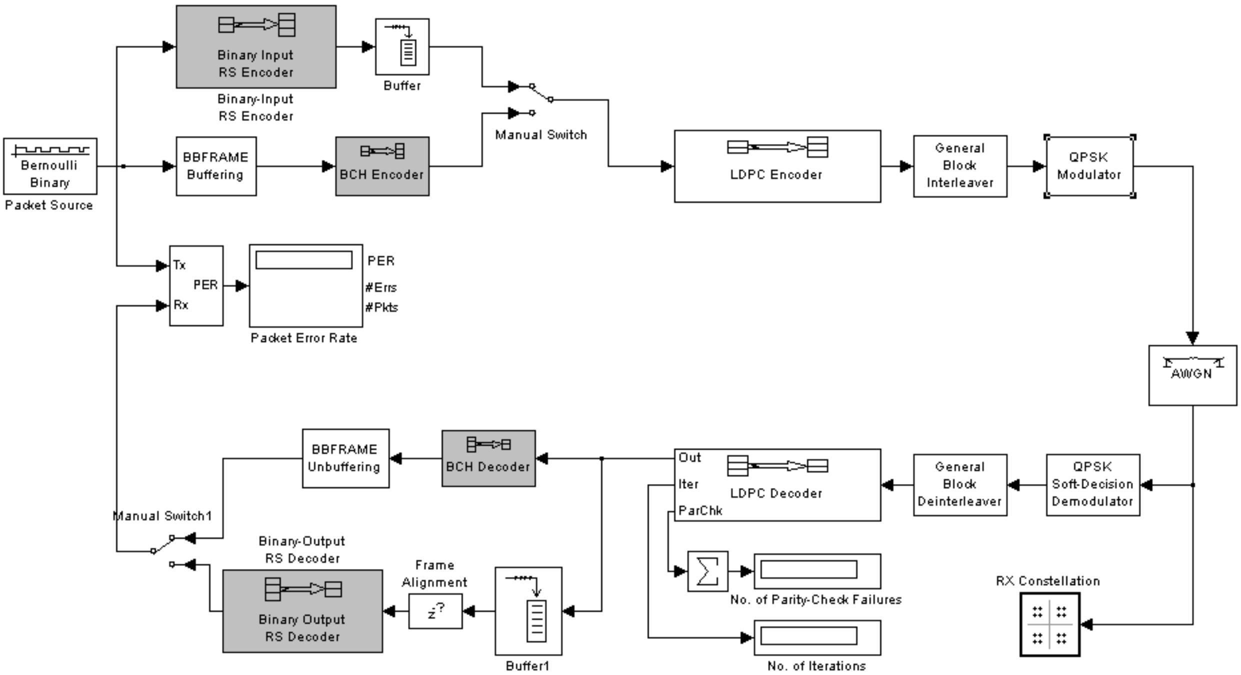

Figure 5. The DVB-S2 Matlab simulation models with BCH or Reed-Solomon outer encoder.

The message to be sent is generated via the random bit generator. The generated bits are encoded by the Reed-Solomon (204, 188) encoder. The Reed-Solomon encoder adds 16 parity bytes after the information bits (Figure 4) of the transport packets. The transport packet after the Reed-Solomon encoding is 204 bytes long. According to (5), the described Reed-Solomon code may correct up to 8 bytes in one packet. The Reed-Solomon coded message is led to the low-density parity-check code block to be encoded.

The maximum number of iterations is set to 50 [1], meaning that the simulation will stop after 50 iterations if the encoded message is not calculated.

The codeword is defined to be of length n=64800 [1].

The encoded message is sent through the Gaussian channel with added white noise meaning that there is only one main path, without any delays. The channel should be quasi-error-free (with BER<10-7) after the outer encoder; after the BCH for the DVB-S2 and the RS outer encoder for the new DVB-S2. In one case, BER falls below 10e-7 and one burst of erroneous bits passed the outer encoder.

At the receiver's side, the received message is demodulated via the QPSK demodulator.

After demodulation, the information is sent to the low-density parity-check decoder. The decoding is based on the concept of belief propagation. It is an iterative process where the information of the received bits is refined iteration by iteration [13]. The maximal number of iteration is set to 50 [1].

The Reed-Solomon decoder performs the outer decoding of message and results in information bits generated at the binary generator (with or without any errors).

For every simulation, the constellation graph is plotted. The bit error rate is calculated as well as the packet error rate. The communication quality may be analyzed by comparing the gained bit error rates and packet error rates for different signal to noise ratios.

IV. SIMULATION RESULTS

Simulation results are gained with simulation models developed with Matlab and Simulink and described before.

Simulation results are calculated for the implemented DVB-S2 Simulink model and for the presented new DVB-S2 model based on the Reed-Solomon outer coding. The type of chosen Reed-Solomon encoder is the Reed-Solomon (204, 188) encoder meaning that the data words of 188 symbols are mapped into code words with length of 204 symbols (Figure 4). The code is designed to correct up to t = 8 symbol errors. The QPSK modulation is chosen. The FEC rates are variable for each simulation. The results are calculated for different noise levels. The first is the noise level where the bit error rate has a quasi-error-free value at the implemented DVB-S2 model. The second is the nearest noise level where bit error rate has no quasi-error-free value; the bit error rate begins to be less than the minimum allowed value. The third noise level is the noise level where the modified DVB-S2 model shows no quasi-error-free value.

Tables 1 – 5 contain representative results from five different simulations.

Table 1 shows that the implemented model of the DVB-S2 system performs quasi-error-free until E_s/N_0 reaches the level of E_s/N_0 = -2.53 dB. When E_s/N_0 = -2.54 dB the bit error rate is no more quasi-error-free and the system is not performing well. The third row in Table 1 presents the performance of the new DVB-S2 model at this SNR. It is shown that the new DVB-S2 model performs quasi-error-free even at E_s/N_0 = -2.54 dB. Therefore, at same SNR the new DVB-S2 model shows better performances. The last row in Table 1 shows that substitution of BCH encoder with Reed-Solomon encoder does not improve the system significantly since the new DVB-S2 model gained a non quasi-error-free performance at noise level of E_s/N_0 = -2.653 dB.

TABLE I. E_s/N_0 PEROFORMANCE AT QUASI-ERROR-FREE, 10E-7 AWGN CHANNEL FOR QPSK 1/4

QPSK 1/4	E_s/N_0 [dB]	Number of simulated bits	LDPC BER
DVB-S2	-2.53	1.62 e+5	0
	-2.54	1.62 e+5	6.173e-6
new DVB-S2	-2.54	1.782 e+5	0
	-2.65	1.782 e+5	5.612e-6

TABLE II. E_s/N_0 PEROFORMANCE AT QUASI-ERROR-FREE, 10E-7 AWGN CHANNEL FOR QPSK 1/3

QPSK 1/3	E_s/N_0 [dB]	Number of simulated bits	LDPC BER
DVB-S2	-1.40	2.16 e+5	0
	-1.41	2.16 e+5	4.64e-6
new DVB-S2	-1.41	2.376 e+5	0
	-1.50	2.376 e+5	3.15e-6

TABLE III. E_s/N_0 PEROFORMANCE AT QUASI-ERROR-FREE, 10E-7 AWGN CHANNEL FOR QPSK 1/2

QPSK 1/2	E_s/N_0 [dB]	Number of simulated bits	LDPC BER
DVB-S2	0.85	3.24 e+5	0
	0.84	3.24 e+5	2.16e-5
new DVB-S2	0.84	3.564 e+5	0
	0.80	3.564 e+5	2.806e-6

TABLE IV. E_s/N_0 PEROFORMANCE AT QUASI-ERROR-FREE, 10E-7 AWGN CHANNEL FOR QPSK 2/3

QPSK 2/3	E_s/N_0 [dB]	Number of simulated bits	LDPC BER
DVB-S2	2.98	4.32 e+5	0
	2.95	4.32 e+5	3.33e-4
new DVB-S2	2.95	4.752 e+5	0
	2.93	4.752 e+5	3.577e-5

TABLE V. E_s/N_0 PEROFORMANCE AT QUASI-ERROR-FREE, 10E-7 AWGN CHANNEL FOR QPSK 3/4

QPSK 3/4	E_s/N_0 [dB]	Number of simulated bits	LDPC BER
DVB-S2	3.96	4.86 e+5	0
	3.94	4.86 e+5	7.61e-4
new DVB-S2	3.94	5.346 e+5	0
	3.91	5.346 e+5	1.871e-6

Table 2 contains simulation results for the QPSK with a code rate of r = 1/3. The implemented model performs well with E_s/N_0 of $E_s/N_0 \geq$ -1.40 dB. When E_s/N_0 becomes lower the system has no quasi-error-free performance any more. It is shown that our model has an allowed bit error rate even with this noise level. Table 2 shows that with E_s/N_0 = -1.40 dB the system has a quasi-error-free bit error rate.

Table 3 shows simulation results for the QPSK with the code rate r = 1/2. The level of noise of E_s/N_0 = 0.85 dB has a bit error rate of satisfactory value. When the noise level becomes higher in system, the model shows a non-error free performance. Again, the new model has a quasi-error-free bit error rate, showing that the Reed-Solomon code could protect more bits from noise interference.

Table 4, showing the simulation results for the QPSK 2/3 leads to same conclusion, the new DVB-S2 model with an outer Reed-Solomon (204, 188) code performs quasi-error-free at noise level where the implemented model gained an unsatisfactory performance.

Table 5 contains the bit error rates for the QPSK 3/4. Again, the new model performed quasi-error-free in surrounding (E_s/N_0 = 3.94) where the implemented DVB-S2 model based on the BCH gained an unsatisfactory results.

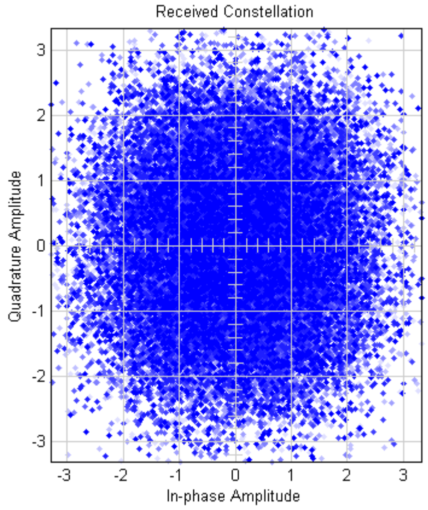

Figure 6. The constellation graph for the existing DVB-S2 Matlab simulation model for the QPSK 1/4 mapping scheme at *Eb/N0* = -2.54 dB.

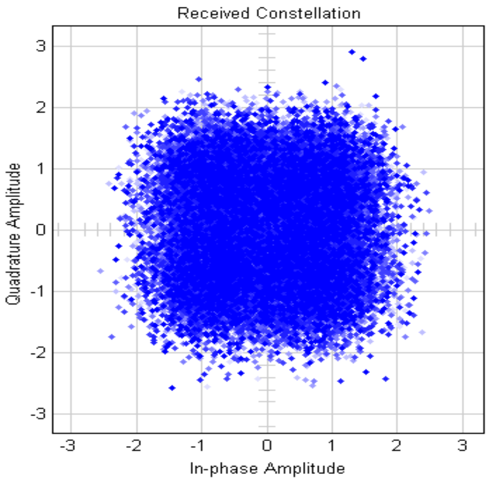

Figure 7. The constellation graph for the new DVB-S2 Matlab simulation model for the QPSK 1/4 mapping scheme at $Eb/N0$ = -2.54 dB.

Simulation results may be analyzed via the constellation graph every simulation resulted with. A representative example of such graphical system performance analyzes is given in Figure 6 and 7. Figure 6 shows the constellation graph for the QPSK 1/4 for the already existing and for the new DVB-S2 model. The results show that the new model performs better since the dots are not so dispersed as they are at the constellation graph for the existing DVB-S2 model.

V. CONCLUSION

This paper presented a new DVB-S2 model based on the Reed-Solomon outer coding since Reed-Solomon code showed to be resistant to burst errors. The type of chosen Reed-Solomon code is the Reed-Solomon (204, 188) code. The Reed-Solomon (204, 188) code maps the data words of 188 symbols into code words with length of 204 symbols. This code can correct up to 8 symbol errors.

Simulation model for the new DVB-S2 is designed with Matlab. Simulation results of the new DVB-S2 model are compared with results gained with an existing DVB-S2 model in Matlab.

The results show that our new DVB-S2 model with the Reed-Solomon (204, 188) code performed better than the existing DVB-S2 model with the BCH outer coding. At E_s/N_0 level, where the existing model gained a non-quasi-error-free performance, the new DVB-S2 model showed better results and a quasi-error-free bit error rate.

The negative aspect of the use of the Reed-Solomon code is a much higher complexity of the Reed-Solomon decoder as compared to the BCH decoder.

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