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Solutions Improve Signal Processing In Digital Satellite Communication Channels

Boiko J.M.

Department of Radio Engineering and Communication
 Khmelnytskyi National University
 11/3 Institutaska Str, Khmelnytskyi, 29000, Ukraine
 e-mail: boiko_julius@ukr.net

Eromenko A.I.

Department of Physics
 Khmelnytskyi National University
 11/3 Institutaska Str, Khmelnytskyi, 29000, Ukraine
 e-mail: sashaf52@mail.ru

Abstract – The paper represented modeling satellite data transmission channel with cascade encoding. The detailed scheme of digital satellite data transmission channel with outer, inner encoder and interleaving was developed. The recommendation for cascade encoder components type and structure was issued. The analytical relationships and research results for describing bit error rate of the cascade turbo-encoder components were represented.

Index Terms – noise stable encoding, concatenated encoding, signal-code structure

I. INTRODUCTION

Satellite data transmission systems are specific at making recommendations to reach the most optimal using noise stable encoding in these systems in order to create a structure of the ground receiving facility, which would process satellite signals. The circumstance to be considered is that input of redundancy at constant data transmitting rate of the source causes reducing symbol duration and also decreasing power per symbol as applied to constant transmitter power. In this case, the error probability BER increases. However the final error probability in decoder output (as shown below) will be less than that in case of not encoded transmission due to error correction while encoding. The energy benefit to be gained while encoding [1] is also the valuable indicator of encoding effectiveness. The paper considers applying methods for noise stable encoding, turbo-codes and concatenated codes with turbo-encoding, which represent various data sequences for its transmission.

II. SIMULATION MODEL OF CONCATENATED ENCODING

To implement codes having high block length and high correcting ability, concatenated codes (CC) are reasonable to use in transmission channel. This case requires using multilevel encoding. The most optimal is two-level scheme. The Reed-Solomon code can be used as the outer one. As to inner code, various codes may be chosen. The conducted research indicated using convolution codes (CnC) as inner ones to be the most beneficial. Using convolution encoders of the following structure is recommended in order to create satellite data transmission channels: $k \leq 7$ - number of data symbols incoming to encoder input per tact, the encoding rate $R=k/n=1/2$ - characterizing redundancy, which is inputted at

encoding. The code (7, 1/2) is transparent to ambiguity. The Reed-Solomon code having block length $n = 255$ is recommended to use for outer encoder. The code has size of data block $k = 223$, the minimal Henning distance [2] is $d = 33$. The code is capable to correct 16 errors. The encoder block-scheme is represented in Fig. 1. The code structure contains 233 data symbols, and 32 testing ones. Generating polynomial in the Galois field may be expressed as $GF(2^8)$. The initial data code combination is expressed by polynomial $F(x) = x^8+x^7+x^2+x+1$. The specific selection of the represented polynomials is first of all entailed by necessary minimizing technical complexity of encoders. The effective way to spacing errors as packs in time is the interleaving procedure. Such disadvantage of convolution interleavers as need to clear memory registers while working on final length data blocks can be eliminated in satellite channel due to transmitting high streams of data, for example when transmitting continuous digital video signal. The structural scheme of the satellite data transmission channel is represented in Fig. 1.

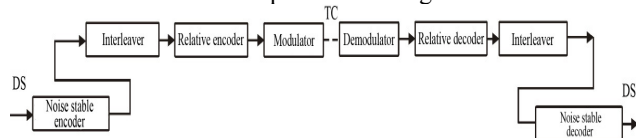


Fig. 1. The structural scheme of the satellite data transmission channel with inner relative encoding and interleaving: TC – data transmission channel; DS – data stream

QPSK-modulation (soft decision) and cascade encoding (using Reed-Solomon code in outer encoder and convolutional (171, 133) code in inner encoder), encoding at $R = 1/2$ rate and decoder Viterbi producing soft and hard decoding algorithms are used in the channel. The data transmission channel is represented by the free space channel, which parameters are set in compliance with parameters of satellite orbit METOP and assuming estimated attenuation and energy budget of data transmission channel. The mentioned estimation is presented more detailed in [2] with the following results: orbit altitude – 837 km, signal loss in free space – 156 dB, receiving station antenna diameter – 2 m, receiver noise temperature – 290 K°. The Simulink model of satellite data transmission system is represented in Fig. 2 in accordance to structural scheme in Fig. 1. Thus, the more is the convective phase noise the more is the error rate in demodulator output and cascade decoder of the

receiving station (the total amount of corrected errors has changed in conditions of experiment in the range from 16 to 13).

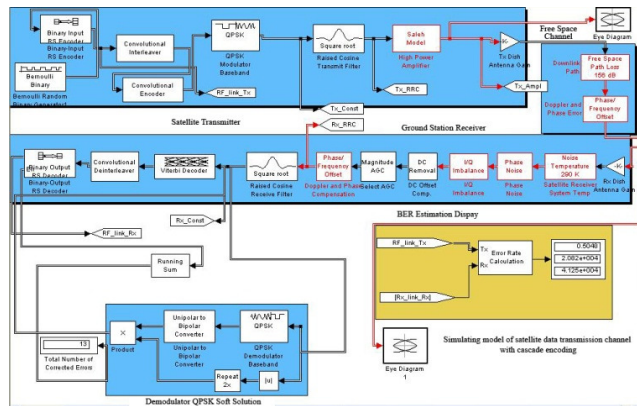


Fig. 2. Simulating model of satellite data transmission channel with cascade encoding

The simulation modeling satellite data transmission channel with cascade encoding (which structure components are: outer encoder Reed-Solomon (255, 223), interleaver, inner encoder – convolutional (171, 133)), QPSK, decoding (soft decision) Viterbi) was carried out in order to estimate energy benefit from cascade encoding and the spectrum characteristics. Modeling was performed on condition that quadrature modulators are synchronized by the phase on both receiving and transmitting data. In particular, figures 3, 4, 5, 6 demonstrate calculated relationships between bit error BER for signal-code structure (SCS) mentioned before and signal to noise ratio (E_b/N_0) for AWGN channel with encoding rate 3/4, 1/2. Thus, the specified code at encoding rate 3/4 has encoding energy benefit $EEB \approx 4.4$ dB ($BER = 10^{-4}$). By shifting encoding rate to 1/2, EEB made 5.9 dB at error level $BER = 10^{-4}$.

Constellation diagrams [1] in receiving and transmitting ends of the satellite digital channel is represented in Fig. 7 a, b.

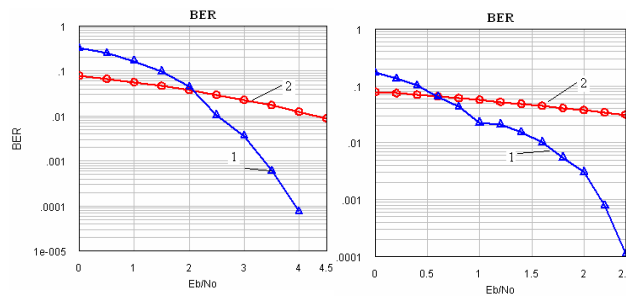


Fig. 3. Bit error BER dependencies in relation to signal to noise ratio (E_b/N_0) for AWGN channel: 1 – CC: (RS (255, 223), CnC (171, 133), QPSK) $R=3/4$; 2 – for not encoded QPSK

Fig. 4. Bit error BER dependencies in relation to signal to noise ratio (E_b/N_0) for AWGN channel: 1 – CC: (RS (255, 223), CnC (171, 133), QPSK) $R=1/2$; 2 – for not encoded QPSK

Figure 8 represents energy spectrum of signals at transmitting and receiving ends of satellite data transmission channel. Besides, we can make conclusion that at increasing encoding rate the energy benefit decreases. The selection of

satellite data transmission channel should be made by applying concatenated codes, optimal for correcting errors, providing redundancy and encoding rate.

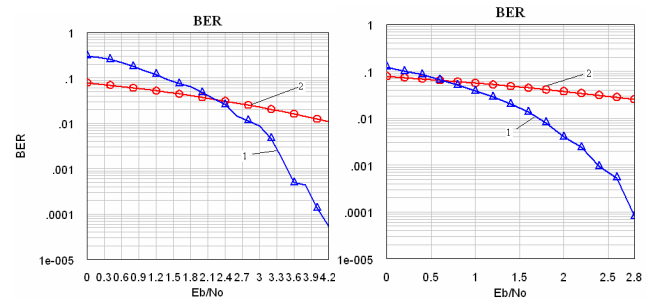


Fig. 5. Bit error BER dependencies in relation to signal to noise ratio (E_b/N_0) for AWGN channel: 1 – CC: (RS (255, 247), CnC (171, 133), QPSK) $R=3/4$; 2 – for not encoded QPSK

Fig. 6. Bit error BER dependencies in relation to signal to noise ratio (E_b/N_0) for AWGN channel: 1 – CC: (RS (255, 247), CnC (171, 133), QPSK) $R=1/2$; 2 – for not encoded QPSK

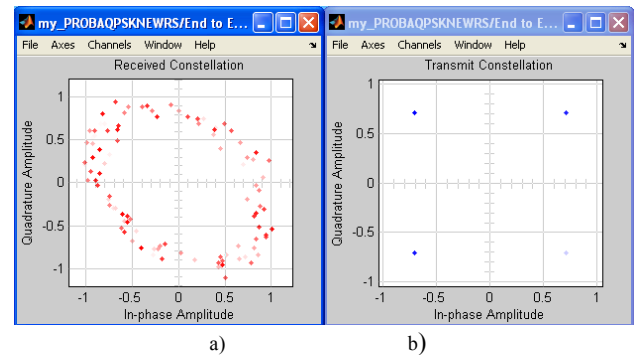


Fig. 7. Constellation – diagram at receiving a) and transmitting b) ends of satellite channel

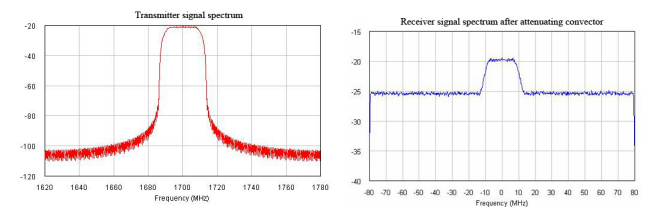


Fig. 8. Energy spectrums of signals at transmitting and receiving ends of satellite data transmission channel with cascade encoding: a) at transmitting end; b) at receiving end after attenuating convector

III. CONCLUSION

Decoding in turbo-encoding systems consists in sending decision-making soft scheme from the output of one decoder to the input of another one and then repeating this procedure until the reliable solution is found. Asymptotic limit for turbo-codes is expressed as:

$$P \geq \frac{1}{L} \cdot Q \left(\sqrt{2d_f \cdot R \cdot \frac{E_b}{N_0}} \right) \cdot \sum_{\omega=1}^L \omega \cdot C_{\omega, d_f}, \quad (1)$$

where L - block size to be interleaved, d_f - turbo-code free distance [2], ω - code weight, C_{ω, d_f} - quantity of the code

sequences of d_f weight, R - encoding rate. The bit error rate [2] was assessed relative to signal/noise ratio for turbo-code TC (37, 21), $L=65536$, $R=1/2$. Fig. 9, a also shows turbo-code asymptotic limit calculated by formula (1). Analysis of relationships shown in Fig. 9 allows making the following conclusions. At the bit error rate less than 10^{-5} the TC characteristics slope lowers at growing E_b/N_0 value, thus the error rate saturation occurs. To reach low bit error rate, for example 10^{-8} , with the help of turbo-code obviously, is possible at high values of E_b/N_0 . Besides, for low bit error rate TC will be ineffective as compared to concatenated codes [2]. Turbo-code having been researched above has the following parameters: quantity of symbols at the encoder input $k=65523$, turbo-encoder structural length $K=5$, interleaver length $L=k+K=65536$, $R=1/2$, code word length $n=L/R=131072$.

Fig. 9, b demonstrates relationship of the bit error rate to the signal/noise ratio (E_b/N_0) for the concatenated code described above, where turbo-encoder was used as inner code, and encoder on the base of the Reed-Solomon code (RS) [2] – as outer encoder; and also for the convolution code (CnC) of the algorithm (CnC (171,133), $R=1/2$) in case of encoding with “soft decision” by Viterbi; for BPSK without encoding; and for turbo-code.

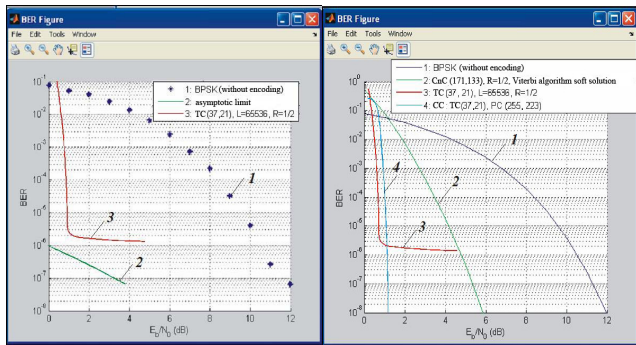


Fig. 9. Relationships of bit error rate to signal/noise ratio (E_b/N_0) for AWGN channel: 1 – without encoding (BPSK); 2 – asymptotic limit; 3 – TC (37,21), $R=1/2$; a) 1 – without encoding (BPSK); 2 – CnC (171,133); 3 – TC (37,21), $R=1/2$; CC: TC (37,21), RS (255,223) - b)

Besides, having analyzed found relationships between bit error rate and signal/noise ratio (E_b/N_0) for the concatenated code we may make the conclusion that concatenated code (curve 4 in Fig. 9) removes saturation effect inherent to TC. The figure 10 shows the curve of BER changing on signal/noise ratio (E_b/N_0) in AWGN for unencoded QPSK (curve 1), and also curve (curve 2) obtained by simulation modeling data transmission channel with cascade encoding of signal/code structure (SCS), which has following type: outer encoder - RS (255, 247), interleaver, inner encoder - CnC (171, 133), QPSK, $R=1/2$. For the mentioned code in case of encoding rate $1/2$ EEB $\approx 2,3$ dB ($BER=10^{-5}$) versus the code of the following SCS structure: RS (255, 247), interleaver, CnC (171, 133), QPSK, which is transmitted at the rate $R=1/2$. In case of switching to data transmission at $1/3$ encoding rate EEB equaled 2.8 dB ($BER=10^{-5}$) versus the similar structure – concatenated code of SCS RS (255, 247), interleaver, QPSK, which is transmitted at the rate $R=1/2$. Changing code structure and encoding rate,

in case of turbo-encoding, brings to increasing EEB. Compared to unencoded phase manipulated signal (curve 1 in Fig. 10) modeling allows obtaining the following values of encoding energy benefit: EEB $\approx 8,5$ dB for $R=1/3$ and EEB $\approx 7,9$ dB for $R=1/2$ at bit error rate ($BER=10^{-5}$) (curve 3 and 4 in Fig. 10).

IV. SCIENTIFIC NOVELTY

The result of the simulation experiment was in obtaining dependence of bit error on E_b/N_0 for variety of cascade signal-code structures.

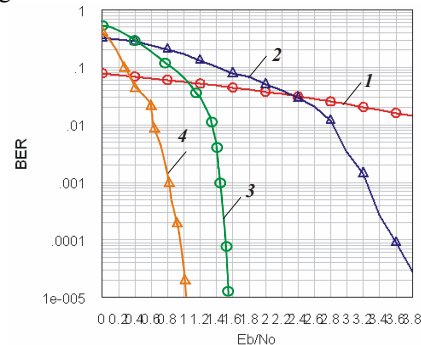


Fig. 10. Relationships of bit error rate to signal/noise ratio (E_b/N_0) for AWGN channel: 1 – without encoding (QPSK); 2 – CC: RS (255, 247), interleaver, CnC (171, 133), QPSK, $R=1/2$; 3 – TC: $R=1/2$, 4 – TC: $R=1/3$

The code structure, encoding rate and also the phase noise influence on EEB and noise immunity of the researched system were defined. The research was aimed at improving ways for data processing in satellite data transmission channel in case of switching to the cascade encoding structure in the channel, and also at assessing the estimated channel energy budget impact on the noise immunity in the system at various configurations of signal code structure. The paper represents recommendations for optimizing data transmission system scheme to improve its noise immunity. The scientific novelty consists in the following statements: combining turbo-code and Reed-Solomon code of the considered configuration (TC+RS) allowed eliminating saturation effect inherent to offered TC and enhancing EEB to 8.5 dB versus unencoded QPSK, or increasing EEB at 4.8 dB versus cascade structure of CnC+interleaver+RS type. The research allows using encoding rate to optimize CnC+interleaver+RS structure. Changing encoding rate from $R=3/4$ to $R=1/2$ allowed enhancing EEB to 5.9 dB. The paper gives assessment of phase noise impact on quantity of corrected errors in the data transmission channel with cascade structure (the amount of corrected errors changed from 13 to 16 in experimental conditions) and conditions enabling to enhance EEB to 5.6 dB ($R=1/2$) by means of changing code structure from RS (255,247) to RS (255,223) in cascade structure.

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